# Human behavioural ecology, anthropogenic impact and subsistence change at the Teouma Lapita site, central Vanuatu, 3000-2500 BP.

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To the best of my knowledge the research presented in this thesis is my own except in the cases where I acknowledge the work of other researchers. This thesis has not been submitted in any form for any other degree at this or any other university.

Stuart Charles Hawkins

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terrible sacrifice but I hope someday you both understand that it's ok to follow your dreams to the best of your ability.

## Abstract

This thesis investigates early Lapita palaeoecological interactions atTeouma, Efate Island, central Vanuatu, and how it changed during a period of transition since first arrival in the region between ca. 3000-2500 BP. Teouma, an early Lapita cemetery and settlement, underwent significant cultural change after the cemetery fell out of use when Lapita culture transitioned into Post-Lapita. Gaps in current knowledge relating to Lapita subsistence adaptations and change have been identified. The reason these gaps exist is complex but simply stated they originate from inherent difficulties with the archaeological record from which only limited methodological and theoretical approaches could be previously employed. Current understanding is therefore vague and incapable of illuminating the variation in subsistence change hinted at in the literature.

Here I take a quantified approach through a human behavioural ecology (HBE) theoretical framework incorporating optimal foraging models (OFM; Prey Choice, Patch Choice and Central Place Foraging) coupled with costly signalling theory to explain optimal and social prehistoric evolutionary behaviour at Teouma. OFM are used to generate predictions of optimal economic behaviour in response to temporal variation in prey abundances. These optimal foraging models (OFM) which typically focus on foraging cultures had to be adjusted to the Lapita mixed economy, which combined foraging within marine and terrestrial resource patches and horticulture. To this end mammal, bird and reptile vertebrate taxa were divided into three broad resource patches (coastal, terrestrial and domestic). OFM predictions and costly signalling theory were then tested using multiple zooarchaeological datasets to demonstrate resource depression, changes in foraging efficiency, mobility between resource patches, and displays of social status. Datasets used included measures of prey diversity, relative abundance, demography, skeletal element representation, and butchery intensity.

The results indicate that Lapita foragers focused initially on high ranked fruit bat and large bodied sea turtle resources in concentrated and predictable proximal locations, which yielded high post-encounter return rates. Giant tortoise exploitation in distant resource patches gained in importance over time as these proximal resource patches became depleted. Domestic patch resources were established and pig abundances increased very quickly but had initially high infant mortality rates. This is likely due to nutritional deficiency and/or selective culling to

reduce associated labour costs or alternatively suckling pigs may have been used in ritualized contexts. Pigs were closely managed and regulated for a range of purposes, which included daily household meat consumption, as well as feasting events that likely served to demonstrate social wealth and power. Bird feathers and turtle shell were likely used to make items denoting social status. Faunal abundances peaked during the later post-cemetery period as Lapita settlement and foraging intensified. This had a huge impact on the terrestrial and coastal resources due in part to direct foraging, forest clearance and invasive commensals. An ecological tipping point followed, which saw the disappearance of crocodiles and a number of fruit bat and bird species from the archaeological record. As encounter rates of high ranked taxa declined so did foraging efficiency and the transition from Lapita to Post-Lapita culture saw a dramatic change in subsistence patterns. Sea turtle nesting sites and giant tortoise resources were devastated around the transition from Lapita to early Erueti culture. Rat demography and the large New Guinea Spiny rat also declined during this transition likely as a result of human predation as settlement intensity appears to have peaked by the end of the Lapita period. At the same time costly pig production also declined likely in response to ecological and social factors and a switch to hunting feral pigs may have occurred during the Erueti phase to improve optimality. These subsistence changes and declines in foraging efficiency appear to have been associated with changes in society and settlement patterns.

"*Lapita economies will not fit a simple dichotomy between strandlooper and horticulture. Instead quantitative studies of faunal abundances will yield a more detailed picture of Lapita subsistence economies*" (Lisa Nagaoka 1988:131).

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# 1 Introduction

This exploratory zooarchaeological research investigates prehistoric ecological interactions at the Teouma Lapita site on Efate Island in the Vanuatu archipelago during the transition from Lapita to Post-Lapita culture. The Lapita culture, a late Holocene Neolithic sea-faring people, expanded rapidly eastwards from the New Guinea region into Remote Oceania as far as Tonga and Samoa. It was one of the last great human migrations during the late Holocene covering a distance of 4500km (Sheppard 2011). During this expansion, sophisticated yet versatile Lapita subsistence economies adapted to a diverse range of tropical island environments and ecologies. Initially, based on limited zooarchaeological evidence, it was thought that terrestrial ecologies were not a significant part of Lapita subsistence (Green 1979) amid debates over Lapita colonizing subsistence strategies that conformed to a clear dichotomy between marine strandlooper's and horticulturalists (see Davidson and Leach 2001). The currently accepted view is that the Lapita substance economy was mixed, based on broad spectrum foraging of marine and terrestrial resources as well as horticulture and animal husbandry established from 'transported landscapes' (Horrocks and Bedford 2010; Kennett et al 2006; Kinaston et al 2014a; Valentin et al 2010).

The combination of swidden horticulture, introduced invasive mammal predators and direct human predation appears to have left a devastating wake on previously uninhabited terrestrial island ecologies eastwards along the colonization path (Prebble and Wilmshurst 2009). Many vulnerable bird and reptile species, initially abundant, became extinct or extirpated sometime after human arrival into Remote Oceania (Steadman 2006a). These extinctions and faunal depletions have been described as a blitzkrieg or overkill by Lapita colonists on naïve fauna (Steadman 1999a) resulting in a shift from optimal foraging of high return species followed by a broadening of the diet base and likely increase in food production (Bedford 2006a). However, elements of Lapita horticultural development in Oceania after Lapita arrival remain unclear (Anderson 2009; Specht et al 2014; Worthy and Clark 2009). Some scholars also question the magnitude of the impact that Lapita people had on island environments due to a lack of a "smoking gun" directly linking humans to the cause of ecological destruction, the difficulty in distinguishing human from natural causes and the reliance on circumstantial evidence (Nunn 2001; Seeto et al 2012).

Prehistoric human impacts on island ecologies have been explicitly linked to initiating subsequent subsistence change in studies from other Pacific Island regions, most notably New Zealand where zooarchaeological traditions and strong theoretical frameworks have been established for a much longer period (Allen 2012; Allen and Nagaoka 2004; Anderson 1981; Nagaoka 2000). The implications of the strong link between changes in subsistence in the Pacific and coinciding changes in other aspects of culture such as technology, material culture and settlement patterns have been advanced by others (Allen 1992a, 1992b; Allen and Nagaoka 2004; Anderson 2002; Anderson and Smith 1996; Kennett et al 2006), as has the evolution of society and the development of powerful chiefdoms (Earle 1987, Kirch 1984; Rolett 1998; West 2007). The implications of subsistence change are far-reaching and it is therefore argued here that subsistence change during the transition from colonizing Lapita populations to Post-Lapita developments is in need of more detailed understanding than we currently possess.

In the region of Lapita expansion many island groups and sites have rather patchy and limited evidence in certain respects due to a range of issues that has served to reduce the zooarchaeological record to a coarse oversimplification of how Lapita subsistence was initially structured and how it changed during the course of Lapita expansion. Sampling issues, preservation conditions as well as limited archaeological records, theoretical frameworks and methodologies have all contributed to this problem and there is a need for more detailed accounts of Lapita/Post-Lapita-ecological interactions over time. Fortunately this is improving all the time with an increasing number of well preserved and undisturbed stratified Lapita and Post-Lapita associated vertebrate deposits recently recovered at various sites in Vanuatu (Bedford 2006a) (including this study), New Guinea (McNiven et al 2011, 2012) and Tonga (Steadman 2006a). In addition, new techniques have recently been developed to provide a direct chemical stable isotopic signature of general non-specific diet (Athfield et al 2008; Bentley et al 2007; Field et al 2009; Jones et al 2009; Kinaston 2010; Kinaston et al 2014a, 2014b; Leach et al 2003; Petchey et al 2014; Valentin et al. 2010), and there is increasing use of archaeobotanical studies to determine the presence of introduced domesticate plants (Crowther 2005, 2009; Horrocks and Bedford 2005, 2009, 2010; Horrocks and Nunn 2007; Kirch 1989; Kononenko 2007; Lentfer and Green 2004; Mathews and Gosden 1997). The potential

for holistic dietary and subsistence behaviour reconstructions involving these multi-proxy datasets has started to gain traction only in the last fifteen years.

Much of this work is being carried out in Vanuatu (Bentley et al 2007; Kinaston et al 2014a; Kinaston et al 2014b; Petchey et al 2014; Valentin et al 2010; 2014), an island chain of volcanic origin formed as part of the Outer Melanesian Arc with a complex geological history (see Gibbons 1985). It is situated approximately 1900km northeast of Australia, 800km west of Fiji, 240km northeast of the Loyalty Islands and 380 km northeast of the Grand Terre of New Caledonia as measured from Aneityum, Vanuatu's southernmost inhabited island. The archipelago is strategically located near the border between Near and Remote Oceania, which is separated by a water gap of 350km at the end of the Solomon's Islands chain. With more than 80 inter-visible islands stretched out roughly 1000km in a long chain north to south, the Vanuatu archipelago was a likely focal point for early Lapita settlement in Remote Oceania (Bedford and Spriggs 2008). This makes Vanuatu a critical location for studying an initial colonizing population in a region previously uninhabited by humans, in contrast to islands in Near Oceania from whence Lapita Culture dispersed from.

The accidental discovery of the Teouma Lapita cemetery and settlement site on the south coast of Efate in central Vanuatu opened up a very significant avenue of Lapita research (Bedford et al 2004). Substantial areal excavations over six field seasons employing very fine grained recovery methods resulted in the collection of a significant quantity of cultural material associated with complex funerary rituals (Bedford et al 2010). Abundant well preserved and largely *in-situ* vertebrate remains, 49212 non-fish specimens in total, were also recovered within stratified midden deposits that relate to the Lapita cemetery and adjacent contemporary Lapita midden, and a post-cemetery settlement that developed after the use of the cemetery. It was during this post-cemetery period when Lapita transitioned to early Erueti culture. These two distinct and yet continuous periods of human occupation spanned a period of time somewhere between 3000-2500 BP (Bedford et al 2006, 2009, 2010; Spriggs and Bedford 2013; Petchey et al 2014).

This thesis is concerned with the underlying motivations of human behaviour with regards to why and how animals were utilized in the past at Teouma. An important aspect of this is distinguishing social-cultural aspects from subsistence based economic

foraging decisions. It explores in detail the complex and changing relationship between the Lapita immigrants and the initially pristine island ecology at Teouma on Efate Island, central Vanuatu and how it subsequently transformed.

More specifically the research questions are briefly outlined here:

1. How did Lapita colonists adapt their subsistence strategies, which developed in different ecological conditions in Near Oceania, to the terrestrial ecology of central Vanuatu during their initial colonization of Remote Oceania?
2. What were the impacts of Lapita subsistence behaviour on the terrestrial and coastal ecology?
3. What role did introduced domestic and commensal animals play in the socio-economy and how did this develop over time?
4. How and why did the Lapita subsistence economy change at Teouma during the early period of prehistoric Vanuatu settlement and what trajectory did it take into the Post-Lapita period?

This is a detailed study of a series of complex human behavioural responses adapting to changing social and ecological conditions. It does this using a combination of evolutionary ecology models including Optimal Foraging Models (OFM) and costly signalling, which is a novel approach to apply to zooarchaeological studies of Lapita economic decisions. Using this approach, it was hoped, would provide more detailed data to establish a more comprehensive explanation of Lapita subsistence change over time.

Evolutionary ecology theory applied to human behaviour (Human Behavioural Ecology) assumes some kind of economic rationalization for subsistence decisions using a set of predictions for subsistence change that can be tested in the archaeological record using OFM (e.g. Smith and Winterhalder 1992; Broughton and O'Connell 1999). The Prey Choice and Patch Choice models predict that high ranked species and high ranked resource patches will be targeted first to maximize foraging efficiency, which typically results in resource depression (Charnov et al 1976). Behavioural responses to this resource depression are usually to intensify resource acquisition within a resource patch (Broughton 1999) or select additional more distant resource patches once return rates in more proximal resource patches decline to a certain point (Orians and Pearson

1979). Realizing the problems with relying solely on evolutionary theory and OFM to explain prehistoric human behaviour, social aspects of human animal use is also explored using costly signalling theory, which purports to explain the motivations of social advancement by hunter gathers (e.g. Codding and Jones 2007; McGuire et al 2007), though never before those of practitioners of swidden agriculture.

Typical of such studies (e.g. Broughton et al 2011) this thesis incorporates multiple lines of zooarchaeological evidence to demonstrate subsistence decisions within the context of changing foraging efficiency. These include the measurement of changes in taxonomic diversity and relative abundance, skeletal element representation, population age structures and large bodied animal processing intensity to reflect changes in ecological biodiversity, foraging efficiency, resource intensification and depression, use of proximal and distant resource patches as well as the presence or absence of indicators of social stratification. The non-fish vertebrate remains, including bird, mammal, and reptile archaeofauna from Teouma, that were quantified by taxa were organized into three general resource patches (terrestrial, coastal, domestic). Abundant fish and shellfish remains from the site have not been included in this study simply due to the fact of time constraints and practicalities associated with PhD research. Fortunately OFM applications are designed to treat individual resource patches as self-contained units of analysis. Temporal changes in Lapita-ecological interactions were tested using a large sub sample (of the total non-fish vertebrate sample introduced above) that incorporated the most appropriate provenance units for spatio-temporal analysis to explore the research questions outlined above.

This thesis is structured into nine chapters including this chapter introducing key concepts, theories, knowledge gaps, goals, methods and materials relating to the Teouma zooarchaeological project that will be discussed in more detail in following chapters. Chapter 2 reviews current knowledge of Lapita colonization and models proposed, limitations in zooarchaeological data and zooarchaeological approaches to understanding Lapita subsistence adaptations, human impacts on terrestrial island ecologies and subsistence change during the Lapita colonization process. Chapter 3 discusses the Teouma site, its surrounding environment and archaeological research. It also discusses the vertebrate assemblages associated with established spatio-temporal contexts and the ecological and resource patch associations with identified taxa. In chapter 4 the theoretical aspects of evolutionary ecology applied to the Teouma

vertebrate assemblages, including OFM and costly signalling theory, are briefly touched upon. Chapter 5 explicitly states the procedures used to capture a multiple array of proxy datasets to test OFM predictions and costly signalling by measuring changes in prey diversity, relative abundance, taxa demography, skeletal element representation and carcass processing intensity. Chapter 6 measures changes in prey diversity and relative abundance for three resource patches (terrestrial, coastal, domestic) to infer changes in foraging efficiency. Chapter 7 looks at changes in the demographic structure of prey to measure more directly the impact of human predation on prey, as well as changes in pig husbandry in the domestic patch. Chapter 8 investigates animal utilization at the individual prey level, using skeletal element representation, to determine intensification of prey body part utilization or distance related cost reduction decisions as well as social-ritualistic symbolic uses of animals. Finally, Chapter 9 presents discussion and conclusions of these results within the context of the current Lapita subsistence debate and illuminates some future avenues of research.

# 2 Biogeographic distributions, Lapita expansion, ecological impact and subsistence change

This chapter, organized into six sections, reviews previous zooarchaeological research including new scientific techniques applied to understanding Lapita subsistence strategies, transitions and the impact of Lapita colonization on ecological systems. This review encompasses the entire region of Lapita expansion while firmly placing the Vanuatu archipelago within this context. During this discourse, key concepts, theories, and methods and how they have developed during the history of Pacific archaeology are evaluated and critiqued. The first section briefly defines the Lapita expansion from Near Oceania to its eastern extent in western Polynesia as an archaeological and cultural entity based on current evidence. The following section discusses the limitations in current datasets that have resulted in only the most general of models for Lapita subsistence change. Section three elucidates Lapita subsistence strategies and how in the past they were linked to cultural historical models of Lapita colonization and expansion. This is followed by a section focusing on the fossil evidence for pre-Lapita fauna and then evidence for Lapita foraging in a range of terrestrial tropical island environments during the colonization process and the impact this had on local ecologies. In section five the evidence for Lapita food production and its link to associated environment change is explored.

## 2.1 The Lapita expansion

Lapita culture first appears in the archaeological record in the Bismarck Archipelago in Island Melanesia (Near Oceania) around 3300-3200 BP (Summerhayes 2010). It is most visible in the archaeological record through its distinctive dentate-stamped pottery style. MtDNA evidence from associated commensal animals (Dobney et al 2008; Larson el al 2007, Lum et al 2006, Matisoo-Smith 2009), and linguistic evidence (Pawley 2002, 2007) indicates Lapita originated somewhere further west in mainland Southeast Asia and Island Southeast Asia (ISEA) before spreading rapidly as a Proto-Oceanic Austronesian community, although the situation was likely to have been far more complex (Donohue and Denham 2010; Specht et al 2014). Some have argued that there is evidence for continuity of some aspects of non-ceramic culture between pre-Lapita

and Post-Lapita periods as part of a continuation of long term patterns of development or introductions in the New Guinea region rather than a sudden arrival of the Lapita cultural complex from ISEA (e.g. Allen and White 1989; Gosden 1992; Specht et al. 2014). This highly mobile oceanic voyaging community (Irwin 2008) represents an easternmost extension of the ISEA Neolithic (Spriggs 2011) that preferred to live in small to large settlements focused on small off shore islands or coastal areas of large islands (Anderson 2001; Lepofsky 1988; Specht 2007).

Before the emergence of Lapita culture the New Guinea region, including Mainland New Guinea and Island Melanesia, had already been occupied during the Pleistocene since around 40-45 ka BP (Summerhayes et al 2009) by small non-intensive, non-Austronesian groups of hunter gatherers (although evidence for Pleistocene arboriculture has been advanced 20-30 ka BP (see Gosden 1995; Latinis 2000; Spriggs 1997). Pre-Lapita Pleistocene groups, in a precursor to Lapita subsistence strategies, trans-located from New Guinea, marsupials and rats in an apparent response to a more depauperate Island Melanesian ecology to what they were accustomed to (Flannery et al 1988). Evidence for the development of agriculture in the New Guinea Highlands during the early Holocene (Denham et al 2004) before Lapita arrival has weakened the earlier concept of Lapita being associated with the first introduction of a range domestic plants as part of a package (e.g. Kononenko 2007; O'Connor 2006) into the New Guinea region, although the evidence does also suggest that early Lapita peoples may have been responsible for the introduction of pigs (*Sus scrofa*), chickens (*Gallus gallus*), the Pacific rat (*Rattus exulans*) and possibly dogs into the New Guinea region (O'Connor et al 2011; Spriggs 1997).

After emerging in the Bismarck's, the Lapita cultural complex then rapidly expanded eastwards to be the first humans to cross a water gap of 350km at the boundary of Near Oceania into Remote Oceania (Figure 2-1), at the end of the Solomon Island chain, simultaneously arriving at the Reef Santa Cruz (Green et al 2008; Sheppard 2011), Vanuatu (Bedford 2006a; Bedford and Spriggs 2008) and New Caledonia (Sand 1999; 2010) island groups in southeast Melanesia by ca. 3100-3000 BP. This was followed quickly by colonization of Fiji (Anderson and Clark 1999; Clark and Anderson 2009; Nunn and Petchey 2013) and then Tonga (Burley 1999; Burley and Connaughton 2007; Burley et al 2012) by about 2900-2800 BP, and Samoa around a similar time (Rieth et al 2008) where the expansion of Lapita colonization reached its eastern limits in western

Polynesia. Spanning a distance of 4500km this was one of the most rapid and far reaching migration events in human history (Sheppard 2011; Spriggs 2011). In a new twist, additional Lapita expansion westwards into mainland southeast New Guinea from the Bismarck's appears to have begun sometime after ca. 2900 BP where later Lapita deposits have been recently excavated at Caution Bay (McNiven et al 2011, 2012) and at Hopo in the Gulf of Papua (Skelly et al 2014).

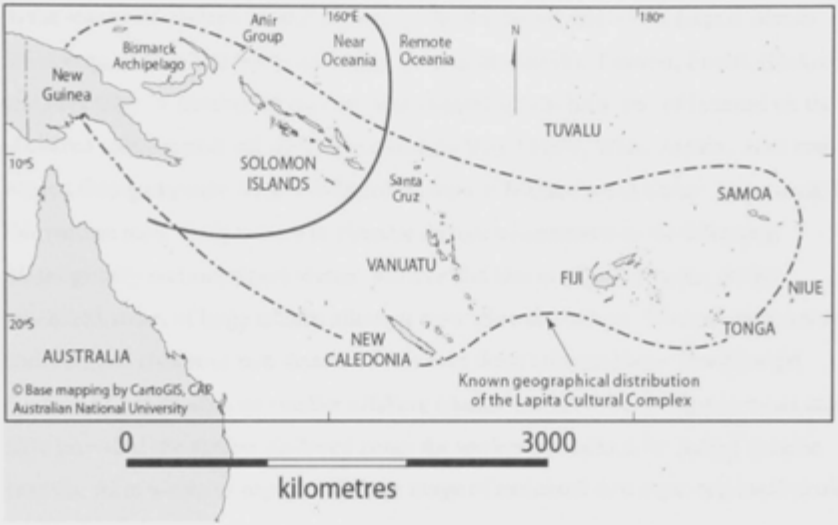


**Figure 2-1: The Lapita expansion**

In Vanuatu, twenty Lapita sites (see Figure 2-2) have to date been located (Bedford and Galipaud 2010), including sites identified on Malo (Galipaud (1998b; Hedrick n.d.), Makue on Aore (Galipaud 2010; Galipaud and Swete-Kelly 2007) Vao, Uripiv, Atchin, Wala Islands off the northeast coast of Malekula (Bedford 2003, 2006a), Malua Bay, northwest Malekula (Bedford 2006a), Erueti (Garanger 1972) and Teouma (Bedford et al. 2006) on Efate, and Ifo and Ponamla on Erromango (Bedford 2006a; Spriggs and Wickler 1989). More recently other Lapita sites have been found at Nerenugman on Motalava in the Banks Islands, Matantas and Port Olry in northeast Santo (Bedford and Spriggs pers com), Shokraon on southern Santo and a Lapita site on Mavea Island on the southeast coast of Santo (Galipaud 2010). Most recently a Lapita site on the southern island of Aneityum has been located and test excavations conducted (Bedford and Spriggs pers com). Their distribution indicates that Lapita settlement was focused along the entire length of the Vanuatu island chain, although the current pattern

suggests sites are most concentrated in the northern and central regions of Vanuatu especially around the larger islands of Santo and Malekula (Galipaud 2011). Galipaud argues, like Hedrick before him, that the earliest period of settlement was focused on the region of southern Santo including the small islands of Aore and Malo (Hedrick 1971, n.d., Galipaud 2011), although this may be partly a result of sampling and site visibility.

These Lapita sites are situated on what are now uplifted beach terraces and are clustered in the south and eastern coastal regions of the windward side of the largest islands Erromango, Efate, and Santo including the Lapita sites Ifo, Teouma, Erueti, Shokraon and Port Olry. A number of sites are also situated on the back end of beaches on the sheltered side of small off shore islets such as Vao, Uripiv, Wala, Atchin, Aore and Mavea facing opposite these windward regions of Malekula and Santo. The reason for this pattern most likely relates to climatic factors summarized in the following biogeography section, where wetter, warmer and less seasonal climates on the windward zones of large islands allows a more diverse ecology. This supports a more concentrated cluster of rich faunal resources in these climate zones. The leeward position of Lapita sites on smaller offshore islands in these rich ecological zones would have provided the perfect sheltered zones for settlement, especially during cyclone seasons, from which to exploit a diverse range of mainland terrestrial and local marine resources.

Understanding cultural diversity in the Pacific has long been a major research focus of archaeologists. Variation seen in Lapita ceramics has led some scholars to designate distinctive Lapita regional provinces (e.g. Kirch 2000) although others (Summerhayes 2000a) argue that the diversity of Lapita across its distribution is a result of chronological development rather than geographical variation. What has become increasingly clear is that Lapita dispersed very rapidly and as a broadly homogeneous cultural entity. Once Lapita populations arrived and established themselves in Remote Oceania, regional diversification developed (Bedford 2006a). The presence of the Near Oceanic Talasea obsidian in the earliest Lapita sites in Remote Oceania, an indication of long distance trade and communication, declined sharply in the Post-Lapita period (Reepmeyer et al 2010). The distinctive dentate-stamped ceramics were in use for only a short period of time, transforming into a range of regionally distinct vessel forms, decorative techniques and motifs across the region (Bedford 2006a; Bedford and

Galipaud 2010; Bedford and Spriggs 2008; Burley et al 1999, 2012; Clark and Anderson 2009; Sand 2010). This suggests changes in social structure; decreasing mobility and long distance travel for social groups and the founding of distinctive independent regional cultures (see Bedford 2006a).

In Vanuatu, during the immediately Post-Lapita period, ceramic sequences diverged along independent cultural trajectories into distinctively separate regional cultural traditions as evidenced on Erromango in the south, Efate in the centre, and Malekula and Santo in the north (for details of ceramic sequences see Bedford 1999, 2000a, 2001, 2006a; Bedford and Clark 2001; Bedford and Galipaud 2010; Galipaud 2011; Spriggs and Bedford 2013). In general ceramics increased in their variability across the Vanuatu region over time, declined in complexity of style, design and form, and in some areas died out completely as in the Centre and South, while in the North, pottery production has continued until the recent past where a reduction in cooking utility and more ceremonial use is documented (Bedford 2001). Pottery is still being produced today in two villages on Santo Island in Northern Vanuatu (Bedford 2006a; Galipaud 2011).

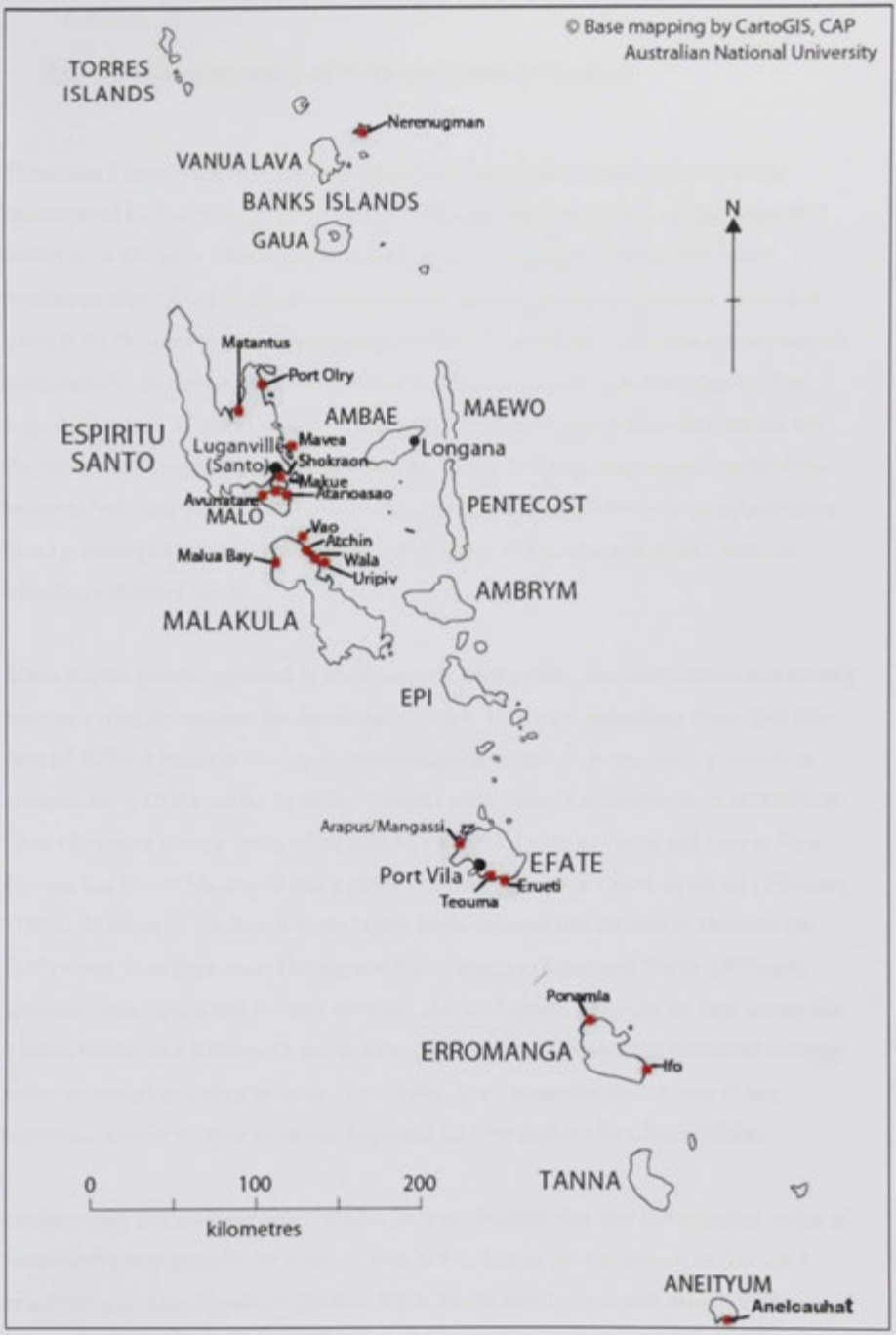


**Figure 2-2: Significant Vanuatu Lapita archaeological sites and the immediately Post-Lapita archaeological site of Arapus/Mangassi.**

## 2.2 Biogeography of Near and Remote Oceania

There was a great variety of tropical island environments and ecological systems encountered by Lapita migrants over the various island groups they settled spanning 4500 km of Oceania. This is an important aspect to consider because ecological conditions affect food production systems and hunter gatherer subsistence behaviour tends to be dictated by prey abundances within an ecosystem. Ecologies themselves are influenced by environmental and climatic conditions as well as human agency. The huge differences in island ecology experienced by Lapita populations throughout the Pacific would have had a profound effect on Lapita foraging adaptations, particularly between Near and Remote Oceania, with regards to crucial differences in colonization history, ecological diversity, abundant naïve fauna, island size and island isolation (Sand and Bedford 2010).

When Lapita people appeared in the Bismarck Archipelago the environment had already been modified by humans for thousands of years. However, estimating this effect has proved difficult because the Lapita archaeological signature is much more visible in comparison with the earlier periods of human settlement (Summerhayes et al 2009). In Near Oceania a diverse array of rat species coevolved with avifauna and bats in New Guinea and Island Melanesia and a range of marsupial species were available (Flannery 1995a). In terms of modern biogeography, biota become less diverse in Oceania the further east from their main Papuan and ISEA sources (Keast and Miller 1996) and terrestrial marsupials and rodents were not able to disperse naturally by land across the 350km border into Remote Oceania. In tropical Remote Oceania the terrestrial ecology today is limited to a diverse array of avifauna, small squamate lizards and volant mammals known to have naturally dispersed into the region (Steadman 2006a).

Archaeology and palaeontology studies have established that this more limited range of biodiversity was actually far more diverse before Lapita people arrived in this once pristine region (see Steadman 2006a). While biodiversity was lower than at its Papuan origin, in the absence of invasive mammals, fauna in Remote Oceania evolved in isolation forming a dense biomass completely lacking in defences against predators. Therefore Lapita migrants to Remote Oceania initially enjoyed higher foraging

efficiencies than that experienced during Lapita settlement of Near Oceania. Lapita subsistence appears to have varied depending on these regional differences in ecology and cultural agency. However, broad patterns of Lapita subsistence adaptations in both Near and Remote Oceania have been identified.

Island geological development had a crucial influence on biogeographical distribution of biota into Vanuatu and how they evolved over time and is said to explain why Vanuatu biota is considered to be depauperate compared to neighbouring New Caledonia, Solomon Islands, Fiji and Tonga (Bauer 1988; 1999; Hamilton et al 2009). Both Vanuatu and the Loyalty islands are considered younger island groups than these surrounding archipelagos, having emerged only 2 and 1.8 million years ago respectively (Hamilton et al 2009; Kroenke 1996; Kroenke and Rodda 1984; Mallick 1975). Whereas New Caledonia is part of the old Gondwana land mass (some 100+ million years old) along with Australia, New Zealand and Lord Howe Island and has a much greater species diversity and vicariance than recently formed volcanic Pacific Islands (Bauer 1999). Much of Fiji and western Polynesia have also had a more extended emergence as Island groups compared with Vanuatu. Fiji in particular emerged ca 35 Mya (Gill 1970). Add to this Vanuatu's more complex geological history, which had the archipelago situated much further to the north closer to Micronesia, more isolated than it is now and therefore less able to receive biotic immigrations (Gibbons 1985). This more complex and recent emergence has been used to explain lower levels of endemism and genetic divergence for Vanuatu and the Loyalty Islands biota (Allison 1996; Bauer 1999; Gibbons 1985; Hamilton et al 2009).

Today Vanuatu sits at a cross roads location which serves as a junction between three routes of biotic immigration (Chew 1975; Fleck et al 2012; Hamilton et al 2009). These three routes of faunal immigration have added to species diversity and the continuous development of endemic fauna in Vanuatu during a very short geological and emergent time frame (Hamilton et al 2009). The main route for species immigration into Vanuatu appears to be from New Guinea through the Melanesian Outer Arc extending through the Solomon Islands chain into Remote Oceania with numbers of species present on any given island group declining with distance travelled east of New Guinea (Allison 1996; Gibbons 1985; Hamilton et al 2009; Keast and Miller 1996; Medway and Marshall 1975). Species dispersal along this route would have been much easier over water for land species and by air for volant species during periods of glacial maximums, when sea

levels were lower, islands larger and distances to travel between islands much smaller. During the last glacial maximum ending around 18000 BP, island numbers and exposed land areas were double what they are now making faunal immigration significantly easier during this period alone (Gibbons 1985).Two other routes of biotic immigration have also been considered important to the ecology of Vanuatu. The old continental source of New Caledonia (Bauer 1988, 1999; Bauer and Sadlier 2000; Keppel et al 2009) and movement back again from Polynesia via Fiji (Gibbons 1985). A distinct faunal break between New Caledonia and Vanuatu as a result of strong currents that allow immigration by water to New Caledonia from Papua and Fiji via Vanuatu but seldom in the opposite direction has limited non-volant immigrants into Vanuatu from this direction (Bauer 1988; Hamilton et al 2010).

Today Vanuatu's naturally dispersed modern fauna consists of a range of mammal, bird and reptile species reflecting this reliance on Papuan immigration. The avifauna of Vanuatu is more completely studied (Brugella 1992, Doughty et al 1999). The herptofauna has been reviewed (Allison 1996; Bauer 1988; Ineich 2011; Medway and Marshall 1975), although a complete up to date field reptile guide for the archipelago is lacking and new species continue to be discovered, or old species reclassified (Fleck et al 2012; Ineich 2008, 2009; Ineich et al 2012; Ota 1998). Mammalian fauna has been reviewed by Flannery (1995b), and Medway and Marshall (1975). Only volant mammals are native to Vanuatu including fourteen bat species present in Vanuatu today, two of which are endemic (Flannery 1995b; Prié 2011). There are currently thirty-six species of reptiles and amphibians present in Vanuatu today when sea snakes are excluded.

Reptile species present in Vanuatu today consist mostly of twenty-seven small squamate lizards (Skinks and Geckos), eight of which are endemic to Vanuatu (Allison 1996:422 Table 7; Ineich 2008, 2009, 2011; Ineich et al 2012, Ota et al 1998). All Vanuatu endemic reptiles are forest closed habitat species (Medway and Marshall 1975), and these small squamate reptiles are not likely to have formed part of the traditional island diet both historically or prehistorically. Other non squamate reptile species include the estuarine salt water crocodile *Crocodylus porosus* present in modern Vanuatu but at the end of its eastern distribution in the Indo-Pacific region with the exception of a few stragglers that get to Fiji and New Caledonia (Allison 1996, Chambers and Esrom 1993). There are two boid snake species *Candoia bibroni* and *Candoia carinata* of

neotropic origins, the latter a recent introduction and the blind snake *Ramphotyphlops braminus* probably historically introduced (Allison 1996). Also present is the small iguanid *Brachylopus fasciatus*, endemic to Fiji having evolved from a neotropic ancestor and recently introduced to Vanuatu (Allison 1996; Bauer 1988). While native frogs never reached Vanuatu, a frog *Litoria aurea* was recently introduced from Australia sometime around the 1960s to try and help control mosquitoes (Bauer 1988). In total 130 (calculated from Brugella 1992 and Doughty et al 1999) bird species have been recorded in the Vanuatu archipelago including 50 sea bird species (27 oceanic, 23 coastal) (many of which are seasonal migrants or rare non breeding vagrants), 20 freshwater aquatic birds from various wetlands, lakes, rivers, and swamps, and 59 terrestrial forest bird species including recent introductions (21 open forest habitat, 38 lowland and montane forest).

Regional ecological variation has also been identified across the Vanuatu archipelago. Climatic conditions including regional precipitation clouds, trade winds, and water temperature appear to have affected biodiversity in Vanuatu. The South Pacific Convergence Zone a low pressure cloud and precipitation band seasonally shifts latitudinally from north Vanuatu in winter to the south during summer resulting in wetter warmer and less seasonal conditions the further north up the island chain one visits (Wirrmann et al 2011a). This is responsible for a greater biodiversity in northern and central Vanuatu compared to southern Vanuatu (Hamilton et al 2010). In addition the trade winds affect rainfall, with the south and east windward sides of Vanuatu islands receiving more moisture than the leeward west and north coast. As an example annual rainfall on Efate is 3000-2400mm per year on the eastern windward side and 1000-1500 on the leeward less humid western side (Wirrmann et al 2011a). In effect on each island there are three climate zones influenced by these trade winds (Quantin 1975). The windward slope zone at low altitude is hotter and wetter. The leeward slope zone is a totally different tropical climate being cooler and drier. Elevation also affects precipitation with the montane zone typically receiving higher precipitation from trade winds and being cooler and more humid (Quantin 1975).

## 2.3 Challenges to demonstrating Lapita subsistence change

A review of the literature highlights the challenges to demonstrating subsistence change during the transition between the Lapita and Post-Lapita periods throughout its expansion. Twenty-seven years ago, Nagaoka (1988) and Butler (1988) reviewed the non-fish and fish fauna respectively from Lapita sites and concluded, as others have argued more recently (Anderson 2009; Specht et al 2014), that models of Lapita subsistence behaviour are marred by insufficient zooarchaeological data to be truly effective. Butler and Nagaoka respectively identified a lack of quantified data as well as limited datasets with various problems including vague reporting and qualified accounts, inconsistent quantification measures, small faunal samples, poor preservation, and varied and often coarse recovery methods. A brief updated review here (see Tables 2-1, 2-2) indicates today that these issues still persist in many studies. Bedford and Sand (2007:3) listed 229 Lapita sites, ranging from small dentate sherd finds to large settlements, but most of these sites had, to date, no faunal remains recovered or reported. This review includes only key Lapita and immediately Post-Lapita sites with significant vertebrate assemblages, both qualified and quantified, from island regions within the area of Lapita expansion. Looking at the zooarchaeological evidence systematically by island group/region, island and site and including stratigraphic records, quantification methods and cultural periods; clear regional patterns, research concentrations and knowledge gaps can be observed.

In the region encompassing Near Oceania only eight sites in Papua New Guinea are considered here for review. In Island New Guinea the sites with the most potential are those in the Mussau Islands in the Bismarck Archipelago, especially Talepakemalai because abundant faunal remains were recovered from undisturbed stratified archaeological deposits (Kirch et al 1991). However, only the bird remains have been reported in any detail (Steadman and Kirch 1998). The fish was analysed and preliminary quantifications published (Kirch et al 1991) and more detailed accounts of fishing behaviour incorporating an expanded set of identified skeletal elements will imminently follow. Excavations at the early Lapita sites on Emirau (Summerhayes et al 2010), Anir and Arawe Islands returned small faunal collections and the details from the latter two sites have yet to be published (Summerhayes 2000a, 2000b; Summerhayes et al 2009). The Watom site is a later Lapita site and shows signs of disturbance, but has the best evidence for pig husbandry at a Lapita site in Oceania (Smith 2000; Green and

Anson 2000). The recent discovery and excavation of Lapita sites at Caution Bay on the south coast of New Guinea has opened up a new avenue of Lapita research where well preserved stratified vertebrate remains have begun to be quantified (McNiven et al 2012), providing preliminary information on Lapita subsistence in this region. Further east in the western Solomon Islands, Late Lapita and immediately Post-Lapita sites, most of which are submerged in the littoral zone, have been discovered which have yet to yield any preserved vertebrate record (Felgate 2003, 2007; Sheppard and Walter 2006; Summerhayes and Scales 2005). Earlier sites may have been destroyed by island subsidence or uplift (Felgate 2003) or the main Solomon Islands may have been leap-frogged by initial Lapita expansion and then later settled by returning Lapita groups from the east (Sheppard and Walter 2006).

Moving into Remote Oceania, the Lapita sites that have been excavated on the southeast Solomon Islands include those in Reef Santa Cruz which comprise faunal assemblages that are either not reported in any detail or have small faunal samples due to the disturbance of parts of the deposits and associated poor preservation (Green 1976). A significant site in the region is SE-RF-2 from which a fishbone (Green 1986) and shellfish (Swadling 1986) sample was analysed and ecological-interactions were described in some detail. The most notable sites in the region are on Tikopia, a small island at the eastern limit of the Solomon Islands region. These sites span the Late/immediately Post-Lapita periods, are well stratified, and comprise one of the largest faunal samples and most detailed study for the Pacific during this period (Kirch and Yen 1982; Steadman et al 1990). The analysis and publication of the fauna from these sites has been for a long time the seminal zooarchaeological work for the period and region.

Before 1995, Vanuatu zooarchaeology was virtually non-existent. Qualified reports by Hedricks (n.d., 1971) from early disturbed Lapita sites on Malo Island in Northern Vanuatu, which offered tantalizing reports of many pig and turtle bones recovered in association with Lapita pottery. A small faunal sample from the Ifo Lapita site on Erromango was quantified (Spriggs and Wickler 1989). Zooarchaeology became more established in Vanuatu during the 1990's and 2000's with a number of stratified Late Lapita or immediately Post-Lapita sites with preserved faunal remains being excavated. Samples tended to be small but quantified faunal assemblages were reported at sites such as Arapus/Mangassi on Efate, Ponamla and Ifo on Erromango, and Yalo, Navaprah

and Malua Bay on the northwest coast of Malekula (Bedford 2000, 2006a). More recently new Lapita sites have been discovered and excavated, but faunal remains continue to be under reported, although this is more to do with small sampling of particular sites or that larger collections are currently under analysis. These sites include Atanoasao, a well preserved stratified site on Malo, where limited areas of the site were excavated. The small amounts of vertebrate remains are presented as weights to class level only (Galipaud 1998). At the well stratified early site of Makue on Aore Island faunal remains have so far been noted but full analysis is on-going (Galipaud and Swete-Kelly 2007). Other sites, not including Teouma, excavated in the last twelve years include four well stratified Lapita/Post-Lapita sites discovered and excavated by Bedford (2003, 2006a, 2007; Bedford et al 2011) on the small offshore islets of Vao, Uripiv, Atchin and Wala off the northeast coast of Malekula where relatively large vertebrate assemblages were recovered. Faunal remains have again been noted (Bedford 2007) but final analysis and preparation for publication is on-going. So to date the lack of zooarchaeological data covering the earliest Lapita period through to the Post-Lapita periods in Vanuatu remains a major gap in the record.

Zooarchaeology began in New Caledonia with Gifford and Shutler's (1956) qualified faunal reports from Lapita sites most notably WKO-013A after which Lapita was first named. Since then a number of sites in New Caledonia and the Loyalty Islands with Lapita and Post-Lapita fish bone assemblages have been analysed including the early colonising sites at Lapita, and St Maurice-Vatcha (Davidson et al 2002). Abundant sea turtle bones were also quantified at St Maurice-Vatcha (NISP=1612; Sand 1999). New Caledonia and the Loyalty Islands is thus one of the best studied island groups for early Lapita marine exploitation in the Pacific, but these sites including Goro (Sand et al 2000) and the St Maurice-Vatcha Lapita sites (Sand 1999) have yet to publish any account of early human interactions with terrestrial fauna. Until this is rectified, this region remains one of the least studied Lapita regions for terrestrial ecological interactions.

In Fiji a large number of Lapita sites have been identified and excavated but most are disturbed shallow deposits (Worthy and Clark 2009). As such the faunal assemblages are rather degraded and small, such as the sites of Naigani (Hawkins 2000; Irwin et al 2011), the open site Wakea 196 on Lakeba (Best 1984; Clark and Szabo 2009; Worthy and Clark 2009), at Yanuca (Hunt 1980, 1981), Kulu Bay on Beqa (Clark and Anderson

2009) and the Naitabale site on Moturiki (Nunn et al 2007). The earliest zooarchaeological studies much like those in neighbouring island groups carried out by Gifford (1951) and Fowler (1955) employed similar methods qualifying taxonomic abundance with few details provided. Cases of misidentification of some Fijian Lapita fauna have also come to light (Worthy and Clark 2009). One site which does stand out in Fiji and in the wider pacific region is the Qaranipuqa rock-shelter 197 on Lakeba which is one of the few well stratified, dated and recorded Lapita sites with quantified fauna in the Pacific, although the faunal assemblage is relatively small (Best 1984; Clark and Szabo 2009; Worthy and Clark 2009). The Lapita site at Bourewa is one of the earliest and most promising sites in Fiji with *in situ* thick midden deposits and three extremely well dated time periods between 2900-2500 BP (Nunn 2007, 2009; Nunn and Petchey 2013). It is one of the largest and most extensive Lapita excavations carried out to date at over 200 $m^2$, and changes in mollusc harvesting has been studied in some detail (Heorake 2009). The vertebrate remains are in the process of being analysed (Sharyn Jones personal communication 2014).

Early excavations in Tonga by Poulsen (1967, 1987) on Tongatapu at Nukuleka were small scale and recovered only very small numbers of faunal remains largely due to very coarse grained recovery techniques. Later small scale excavations were undertaken across the archipelago at the Niuatoputapu NT-90 site (Kirch 1988; Kirch and Dye 1979) Fakatafenga on Tungua Island and Tongoleleka on Lifuka Island (Dye and Steadman 1990). It wasn't until research by Burley and others (Burley 1998, 1999, 2001; Burley et al 1999, Burley et al 1995, 2001; Burley and Connaughton 2007; Burley and Dickinson 2001) in the Ha'apai group and again at Nukuleka (To-2, To-5), when substantial faunal remains were recovered. On Ha'apai during this phase of research a number of small scale 9-12$m^2$ excavations (Touma'a Well, Tongoleleka, Feleloa, Pukotala, Mele Havea, Vaipuna, Holopeka) of *in situ* well preserved deposits spanning the Lapita and overlying Polynesian plainware periods were conducted. Although these were partially disturbed by later pits associated with continuous village activity they could be interpreted chronologically using an undisturbed plainware site at Holopeka (Burley et al 1999). Burley's excavations typically were conducted using a fine grained sieving strategy using fine mesh sizes (but not explicitly explained in any more detail) and these excavations have yielded 100000+ fish, reptile, bird and mammal vertebrate remains (Pregill and Steadman 2004) of which the bird and reptile fauna from many of these sites has been both analysed in detail and published (Pregill and

Steadman 2004; Steadman et al 2002a, 2002b; Steadman 2006a). Three more promising stratified Lapita/Post-Lapita sites have since been discovered and tested on the Vava'u Islands in the North (Burley and Connaughton 2007) with the non-fish fauna in the process of being analysed, while the fish has recently been quantified (Densmore 2010). Despite issues with stratigraphy and small areas of excavation, the discovery of well-preserved deposits spanning the Lapita and Post-Lapita periods combined with the systematic sampling strategy employed by Burley and Steadman in this region has made it the most productive region in terms of understanding Lapita interactions with terrestrial ecologies.

Samoa and American Samoa have only one confirmed Lapita site, a submerged site at Mulifanua where no fauna was recovered. Other sites, such as To'aga on Ofu Island in American Samoa, had a very good quantified study of abundant, mostly fish, vertebrate remains but also including some extinct or extirpated bird species (Nagaoka 1993; Steadman 1993a). To'aga dates to a similar period to Lapita but dentate-stamped pottery was not present (Kirch and Hunt 1993) and this was likely an immediately Post-Lapita site.

In summary some regions appear to have been differentially sampled creating gaps in our knowledge of Lapita subsistence across its full expansion. Preserved Lapita vertebrate assemblages have yet to be found in the main Solomon Islands chain, and there is only one Lapita site in Samoa sans vertebrate remains. These regions are major gaps in the Lapita zooarchaeological record. In New Caledonia and Fiji in particular there are problems of preservation and sampling and there needs to be a much greater research focus on early terrestrial adaptations. In the early stages of Vanuatu research there was little faunal material found or reported in detail in the few known Lapita sites. A number of sites have since been found with substantial remains recovered but detailed analyses are on-going.

Generally there are a range of problems that have resulted in only the most general descriptions of Lapita subsistence behaviours and Post-Lapita transitions. These problems include small sample sizes, small scale excavations and a general lack of reporting of faunal remains. After an acceleration of intensive research in the past twenty-five years ongoing analyses still in progress will soon rapidly overcome these issues. Most Lapita sites also have complicated post depositional histories with

preservation issues. Differential taphonomic issues act on most faunal assemblages from Lapita sites, which are often shallow, mixed, or submerged intertidal archaeological deposits. These have often been subjected to agricultural disturbance, bio-turbation, acidic water saturation from rainfall, coastal erosion (see Anderson 2009; Bedford 2006a; Green 1979) and acidic soils such as those at Ambitle (White and Specht 1971). In most cases little or no bone at all is recovered from these sites and the few bones that are recovered are in very poor condition. These are all significant factors in relation to sampling issues and the recovery of adequate and representative faunal samples for regional studies. To conclude, fragmented and small faunal assemblages and a lack of well-preserved stratified *in-situ* deposits is a common trend in the Pacific.

The few quantified studies on Lapita faunal remains to date tend to report a list of taxonomic identifications only and sometimes focusing only on a few taxa. For example the Tongan research focuses on the novel bird and reptile fauna that went extinct sometime after Lapita arrival (Steadman 2006a). Many studies do not offer any analysis on skeletal element frequency, taphonomy or changes in animal demography which could offer a greater wealth of information regarding Lapita-ecological interactions. A few have included some of these analyses for non-fish fauna notably the work by Steadman and Pregill in Tonga on bird and reptile fauna (Pregill and Steadman 2004; Steadman et al 2002b), while fish faunal analysis often includes skeletal element frequencies but usually to demonstrate methodological procedures rather than to gain a greater understanding of fishing behaviour (e.g. Clark and Szabo 2009; Green 1986; Hawkins 2000).

Previously, small or biased samples have been in large part the result of varied recovery methods which have improved dramatically in the past twenty-five years but still vary from site to site. This variety of recovery methods and reporting is important when considering the biases in recovery of vertebrate remains particularly towards larger bone specimen. This may account for variation in interpretive zooarchaeological datasets and making cultural practices difficult to account for when comparing fauna from a range of sites. In the early stages of Pacific archaeology, recovery methods were quite coarse using large mesh sizes or not employing sieving at all (e.g. Garanger 1972; Gifford and Shutler 1956; Poulsen 1967). In many cases recovery methods are not mentioned explicitly (Bedford 2006a, Bedford et al 2006; Nunn et al 2007, Galipaud and Sweet-Kelly 2007; Sand et al 2000; Sand 1999, see Butler 1988; Nagaoka 1988 for earlier

examples) making it difficult to assess the integrity of the faunal sample and the validity of subsistence interpretations.

Recovery methods have become much finer in more recent studies. The potential of wet screening sediment through fine mesh sizes appears to be the biggest advancement towards recovering larger faunal samples with a greater diversity of taxa. A good example of this was the employment of wet screening through fine mesh at Kulu Bay and Votua in 2000 compared to other Fijian excavations, including Votua 1996, where sample size and species diversity was greatly increased (Clark and Szabo 2009). Even a change from dry sieving to wet sieving through a coarse 5mm mesh during the Naigani excavations, due to a change in weather conditions, resulted in a greater recovery of faunal remains (Hawkins 2000). This indicates how advantageous wet screening is, bones become more visible as fine sediment is washed through the sieve, reducing biased sampling and increasing representation of small animal species in Lapita assemblages. These fine grained recovery methods have recently been employed during excavations of Lapita era sites at Caution Bay on the southeast coast of New Guinea (McNiven et al 2011, 2012), New Caledonian Lapita sites (Davidson et al 2002) and also in Vanuatu on the Arapus/Mangassi and Teouma sites on Efate and the Lapita sites onVao and Uripiv Islands.

Finally problems with chronological control need to be mentioned. Lapita transitions to Post-Lapita periods are poorly defined time periods which appear longer then they probably are due to the flat part of the calibration curve at key periods. For example at Caution Bay along the southeast coast of New Guinea this effect has resulted in large age ranges from 2900-2350 BP (McNiven et al 2011, 2012) stretching out the length of Lapita occupation which is likely to have been much shorter. Similar issues exist in Vanuatu (Bedford 2006a). This presents a unique challenge to presenting time intervals within stratified deposits that could inform on distinct periods of subsistence behaviour to interpret change over time. Demonstrating distinctive stratigraphic and/or age depth relative spatio-temporal units with unknown absolute ages during the transition from Lapita to Post-Lapita culture is the most viable means for demonstrating fine grained changes in culture.

**Table 2-1: Archaeological sites, New Guinea, Solomon Islands, and Vanuatu with reported vertebrate remains from Lapita to Post-Lapita contexts**

| Region/Island group | Site | NISP | MNI | Recovery method | Period | Reference |
|---|---|---|---|---|---|---|
| **Papua New Guinea** | | | | | | |
| Mussau | ECA/ECB/ECQ | 21790 | n/a | 6.4mm | Lapita/Post-Lapita, Stratified sites | Kirch et al 1991, Steadman and Kirch 1998 |
| Emirau | EQS | 1862 | n/a | 7mm | Lapita | Summerhayes et al 2010 |
| Anir | Kamgot | n/a | n/a | n/a | Lapita/Post-Lapita | Summerhayes 2000b |
| Arawe | all sites | n/a | n/a | n/a | Lapita/Post-Lapita | Summerhayes 2000a |
| Watom | SAC | 1453 | n/a | 5mm | Late Lapita/Post-Lapita | Smith 2000, Green and Anson 2000 |
| Siassi | KLK | 47 | n/a | 10-12mm, 6mm | Lapita | Lilley 1986 |
| New Guinea | Edubu 1 | 482 | n/a | wet 2.1mm | Late Lapita | McNiven et al 2012 |
| New Guinea | Bogi 1 | n/a | n/a | wet 2.1mm | Late Lapita | McNiven et al 2012 |
| **Southeast Solomon Islands** | | | | | | |
| Nendo | SE-SZ-8 | n/a | n/a | n/a | Lapita | Green 1976 |
| Reef Santa Cruz Islands | SE-RF-6 | n/a | n/a | n/a | Lapita | Green 1976 |
| Reef Santa Cruz Islands | SE-RF-2 | 882 | n/a | 5mm | Lapita | Green 1976, 1986 |
| Tikopia | all sites | 35000+ | n/a | 6.4mm | Late Lapita/Post-Lapita, Stratified sites | Kirch and Yen 1982 |
| **Vanuatu** | | | | | | |
| Santo | Port Olry | n/a | n/a | n/a | Lapita partly disturbed | Unpublished |
| Malo | NHMa-7 | n/a | n/a | n/a | Lapita/Post Lapita, Disturbed surface | Hedrick and Shutler 1969, Hedrick 1971, n.d. |
| Malo | NHMa-8 | n/a | n/a | n/a | Lapita/Post Lapita, Disturbed surface | Hedrick n.d. |
| Malo | NHMa-101 | n/a | n/a | n/a | Lapita/Post Lapita, Disturbed surface | Hedrick n.d. |
| Malo | Atanoasao | n/a | n/a | n/a | Lapita/Post-Lapita Stratified | Galipaud 1998 |
| Aore | Makue | n/a | n/a | n/a | Lapita/Post-Lapita Stratified | Galipaud and Swete-Kelly 2007 |
| Malekula | Yalo MK-3-48 | 1209 | n/a | n/a | Post-Lapita | Bedford 2006a |
| Malekula | Navaprah MK-3-47 | 2001 | n/a | n/a | Post-Lapita | Bedford 2006a |
| Malekula | Malua Bay | 121 | n/a | n/a | Late Lapita/Post-Lapita | Bedford 2006a |
| Vao | | n/a | n/a | wet 1-2mm | Lapita/post Lapita | Bedford 2006a, Bedford et al 2011 |
| Uripiv | | n/a | n/a | wet 1-2mm | Late-Lapita/Post Lapita | Bedford 2006a, Bedford et al 2011 |
| Atchin | | n/a | n/a | n/a | Lapita/Post Lapita | Bedford 2006a |
| Wala | | n/a | n/a | n/a | Lapita/Post Lapita | Bedford 2006a |
| Efate | Arapus/Mangassi | 5566 | n/a | n/a | Immediately Post-Lapita stratified | Bedford 2006a, MacDonald 2002 |
| Erromango | Ponamla | 2712 | n/a | n/a | Immediately Post-Lapita stratified | Bedford 2006a |
| Erromango | Ifo | 281 | n/a | n/a | Lapita/Post-Lapita stratified | Bedford 2006a |

**Table 2-2: Archaeological sites, New Caledonia, Fiji, Tonga, and Samoa with reported vertebrate remains from Lapita to Post-Lapita contexts**

| Region/Island group | Site | NISP | MNI | Recovery method | Period | Reference |
|---|---|---|---|---|---|---|
| **New Caledonia and Loyalty Islands** | | | | | | |
| Grand terre | Lapita | 651 | 313 | wet 3mm | Lapita | Davidson et al 2002; Gifford and Shutler 1956 |
| Grand terre | Goro | n/a | n/a | wet 3mm | Lapita/Post-Lapita | Sand et al 2001 |
| Isle of Pines | St Maurice-Vatcha | 1827 | 82 | wet 3mm | Lapita/Post-Lapita | Davidson et al 2002; Sand 1999 |
| Mare | Kurin | 19 | 12 | n/a | Lapita/Post-Lapita | Sand et al 2002 |
| **Fiji** | | | | | | |
| Mago | Votua | 1377 | | wet 3mm | Lapita single phase | Clark and Szabo 2009; Worthy and Clark 2009 |
| Yanuca | VL16/81 | n/a | 46 | n/a | Lapita | Hunt 1980, 1981 |
| Moturiki | Naitabale | 663 | | n/a | Lapita stratified with some disturbance | Nunn et al 2007 |
| Naigani | VL21/5 | n/a | n/a | 2.5, 3.5, 7.1mm | Lapita | Best 1981; Kay 1984; Irwin et al 2011; Hawkins 2000 |
| Beqa | Kulu Bay | 3032 | | wet 2mm, 4mm | Lapita/Post Lapita | Clark and Szabo 2009, Worthy and Clark 2009 |
| Lakeba | 196 Wakea | 0 | 149 | 2.5, 5, 9mm | Lapita/Post Lapita disturbed | Best 1984, Worthy and Clark 2009 |
| Lakeba | 197 Qaranipuqa | 0 | 194 | 2.5, 5, 9mm | Lapita/Post Lapita stratified | Best 1984, Worthy and Clark 2009 |
| Cikobia | all sites | n/a | n/a | n/a | Lapita/Post Lapita | Leach et al 2000 |
| **Tonga** | | | | | | |
| Niuatoputapu | NT-90 | 935 | | 6.4mm | Lapita/Post-Lapita | Kirch 1988; Kirch and Dye 1979 |
| Vava'u | all sites | n/a | | n/a | Lapita/Post-Lapita | Burley and Connaughton 2007; Densmore 2010 |
| Tongatapu | To-2 | 89 | | n/a | Lapita single period secondary deposit | Burley et al 2001 |
| Tongatapu | To-5 | 27 | | 6.4mm | Lapita | Poulsen 1987 |
| Lifuka, Ha'apai | Toumu'a Well | 40 | | n/a | Immediately Post-Lapita | Steadman et al 2002a |
| Lifuka, Ha'apai | Holopeka | 130 | | n/a | immediately Post-Lapita | Burley et al 1999; Steadman et al 2002a |
| Lifuka, Ha'apai | Tongoleleka | 466 | | n/a | Lapita | Pregill and Steadman 2004; Steadman et al 2002a |
| Tungua, Ha'apai | Fakatafenga | n/a | | n/a | Lapita | Dye 1988 |
| Ha'ano, Ha'apai | Pukotala | 77 | | n/a | Lapita | Pregill and Steadman 2004 |
| Ha'afeva, Ha'apai | Mele Havea | 25 | | n/a | Lapita | Pregill and Steadman 2004 |
| Uiha, Ha'apai | Vaipuna | 25 | | n/a | Lapita | Pregill and Steadman 2004 |
| Foa, Ha'apai | Faleloa | 1052 | | n/a | Lapita/Post-Lapita stratified | Steadman et al 2002a; Pregill and Steadman 2004 |
| **American Samoa** | | | | | | |
| Ofu | To'aga | 10211 | | 6.4mm | Immediately Post-Lapita | Kirch and Hunt 1993; Nagaoka 1993; Steadman 1993 |

## 2.4 Lapita subsistence change models

Allen (1992a) noted that Pacific island subsistence behaviour has been classified as either specialising on a few resources or generalized and focused on a broader range of taxa. The former (specialised) is associated with high return but less stable subsistence economies, while the latter (general) are considered lower risk but lower return. This has been the case for Lapita archaeology where earlier models of Lapita subsistence behaviour were linked to culture historical models of colonization (Best 2002; Clark and Terrell 1978; Green 1991, 2003; Groube 1971). Two main competing subsistence strategies were advocated creating a sharp dichotomy and oversimplification between foraging and food production between pre-Lapita, Lapita and Post-Lapita periods, similar to those created in other Neolithic cultures around the word (Terrell et al 2003).

Serious debates began in the 1970s. Groube (1971) argued, based on the presence of extensive shell middens in Tonga, for a highly mobile specialized Lapita economy, which he termed "strandlooper" after the cultures of coastal southwest Africa, which was focused on abundant marine resources (see Davidson and Leach 2001 for a summary). It was surmised that once a marine resource patch was depleted, settlement would simply be moved to a new un-depleted area or region, while only later migrants established an agriculturally based subsistence economy. This was incorporated by Clark and Terrell (1978) into one of their four possible Lapita colonization models implying that a strandlooper strategy could be the cause of rapid Lapita dispersal based on classic pull factors. Such a model of colonization supports the fast train model (Kirch and Hunt 1988) of Lapita expansion which once argued for more or less rapid and synchronous movement from the Bismarck Archipelago to its eastern most extent in Tonga and Samoa. The problem with this model was that it assumed that settlements must be briefly occupied and abandoned once marine resources were exhausted, but many Lapita sites and areas actually saw persistent settlement and the development of unique Post-Lapita cultures (e.g. Bedford 2006a; Best 1984; Burley 1999).

The second competing Lapita subsistence strategy proposed at a similar time was generalist in nature incorporating a marine foraging strategy combined with an introduced horticulture package including domesticated animals and plants (Green

1976, 1979). This idea was further expanded, refined and tied into Green's (1991, 2003) Triple I Lapita colonizer model. It suggested that the Lapita people favoured a low risk set of subsistence practices designed for successful colonization and able to be adapted to a range of island environments. Subsistence change typically is described as developing *in-situ* in response to declines in local wild resources and ecologies and the development of agriculture over time. The key problem with this model initially was that it relied on indirect evidence to infer Lapita agricultural production, including limited numbers of pig bones and artefacts from early Lapita sites in Mussau, southeast Solomon Islands and Tonga (Green 1976, 1979, Kirch 1988; Kirch and Yen 1982), macrofossil plant remains (Kirch 1989) as well as linguistic evidence tracing horticulture origins back to ISEA (Pawley 2002). The issue of horticultural packages and how complete or not they were in different regions of Oceania at different times remains contentious because in many regions, evidence for a whole range of supposed items that might be part of such a package have yet to be identified. An example of this is the on-going debate as to whether pigs came with Lapita colonisers to Fiji and Tonga (Anderson 2009; Clark and Anderson 2009).

The whole rationale for introducing transported agricultural landscapes that were required to survive in marginal Remote Oceanic landscapes, can also be called into question. Non-Austronesian Pleistocene hunters and gatherers appear to have managed to survive for up to 40-45 ka BP on tropical islands in Island Melanesia subsisting on low level arboriculture and foraging largely without the type of Lapita horticultural economy typically described (Spriggs 1997). But Spriggs (2000) has argued that this was not possible in Remote Oceanic islands such as Vanuatu. He suggested that rather than due to any limitations in voyaging capability, this region was not settled by pre-Lapita people because it lacked major cultigens suitable for human consumption to sustain a successful colony. This situation may have placed a great strain on maintaining a balanced healthy diet, in the absence of sustainable sources of carbohydrates and/or fat (Davidson and Leach 2001). But the presence of wild carbohydrate sources from endemic edible leafy plants in the region (McClatchey 2012; Walter and Lebot 2007) suggests that this may not have been as big an issue as these arguments have suggested, and it may have been possible to survive on these islands without introduced cultigens once populations made the journey. Other aspects of historically contingent socio-political values adapted within different social and ecological contexts of ISEA and New Guinea as well as gender or socio-political

divisions within society may need to be considered when assessing the development and spread of Lapita horticultural systems.

By the turn of the 21st century, after thirty years of sustained research, questions were being asked if the data could fit the strandlooper or fast train colonization model (Kennett et al 2006; Kirch 2000; Spriggs 1997). Some have argued that the evidence suggested a more gradual episodic Lapita expansion while a diverse array of subsistence strategies were adapted to a range of environments (Bedford 2006a; Burley et al 2001; Kennett et al 2006; Kirch 1997, 2010; Sand 2010; Sand and Bedford 2010; Spriggs 1997). These appeared to fit Green's (1991, 2003) Triple I intrusion, innovation and integration model of Lapita development and expansion using a generalist low risk subsistence strategy. Green's model for Lapita subsistence is now better known as the mixed economy where a combination of broad spectrum marine and terrestrial foraging was combined with the establishment of low levels of food production in newly colonized regions which may have expanded and intensified over time (e.g. Bedford 2006a; Burley et al 2001; Kennett et al 2006; Valentin et al 2010).

In Island New Guinea it has been argued that once Lapita mixed economies became established they developed a greater focus on agriculture over time. As landscapes were modified to improve agricultural production more intensive horticultural systems became established (Summerhayes and Allen 2007; Summerhayes et al 2009). The same argument is applied to Remote Oceania but with some key differences as a result of ecological disparities between the two regions. It has been argued that the lack of edible vegetables and abundant terrestrial and marine faunal resources available to Lapita people on arrival in Remote Oceania resulted in an initial uneven focus on these local protein and fat resources (Anderson 2002). It is believed that a short time after initial colonization, the generalist mixed Lapita subsistence economy was established as resource depression of terrestrial and marine fauna occurred and introduced horticultural resources were developed taking on an increasing proportion of the diet over time (Bedford 2006a; Kennett et al 2006).

These models are still largely general and lacking in explicit theoretical frameworks using quantified data. Kennett et al (2006) were the only researchers to conceptualize Pacific subsistence and colonization within a theoretical framework, albeit using qualitative data. They argue that Lapita settlement and subsistence economies

developed in response to spatially varied ecological conditions as predicted by the Ideal Free Distribution Model within a Human Behavioural Ecology framework. The model predicts how organisms distribute throughout multiple resource patches or regions by choosing to forage in patches of the highest quality, which have the most abundant resources. It assumes that organisms have ideal information on the relative quality of resource patches and that they freely distribute between them. In the absence of quantified data, qualified data used by Kennett et al (2006) included Lapita settlement patterns and chronology, subsistence economy generalizations, estimated regional resource patch quality and anthropogenic impacts on resource patch suitability. Based on these data, they argue further that push factors such as population growth facilitated by food production, environmental and ecological degradation, and possibly territorial conflict best explain what they termed the episodic discontinuous archaeological evidence for Lapita dispersal and settlement. While they may have only been able to offer generalized statements, it was a useful exercise in developing a hypothesis on Lapita settlement and subsistence economy during the Lapita expansion.

However, the chronology of Lapita settlement is constantly being debated and proponents of instantaneous expansion have argued that the time depth of Lapita expansion appears shorter and the pace of colonisation more rapid making the archaeological record appear less episodic. Geographical mobility is increasingly becoming prominent in disscussions of Lapita colonisation as the movement of peoples during this period appears far more intricate then previous models have suggested (Specht et al 2014).

In the not too distant past it was difficult to demonstrate the transition from broad spectrum foraging to the establishment of food production systems. Increases over time in pig bone relative abundance were usually used as a proxy for agricultural intensification in the Pacific (e.g. Kirch and Yen 1982, Rolett 1998; West 2007; Summerhayes and Allen 2007). This is based on ethnographic accounts demonstrating that the maintenance of larger pig herds require an increased investment of harvested vegetables (e.g. Hide 2003). The most effective study to date at demonstrating the transition from initial Lapita colonization subsistence to later developments was that of Kirch and Yen (1982) at Tikopia. They argued using abundant vertebrate remains that resource depression and extinctions resulted in proportionately greater pig utilization relative to wild meat sources over time. However, an overall decline in meat

consumption occurred, which probably coincided with an increased dietary reliance on established crops. There is a difference in pig bone abundance between early Near Oceania Lapita sites in the Mussau (Kirch et al 1991), Arawe and the Anir Islands (Summerhayes and Allen 2007), which typically recovered small quantities of pig bone relative to the abundant pig bones found at the later Lapita site on Watom (Smith 2000). Summerhayes and Allen (2007) argue this indicates increased agricultural output over time during Lapita settlement of Near Oceania. However, there are arguments that the unilinear progression of agricultural intensity is not assured. This was based on a variety of cultural and ecological factors and the difficulty in characterizing horticultural economies based on reductionist typologies (Smith 2001; Terrell et al 2003). These factors when combined with the patchy and ambiguous zooarchaeological record (Specht et al 2014) only serve to obscure the picture.

More recently, the potential of combining multidisciplinary complementary studies incorporating zooarchaeology, archaeobotany and stable isotopic data to provide unprecedented levels of detail on prehistoric diet, mobility and society is starting to be realised (Kinaston et al 2014a, 2014b). A notable interdisciplinary study was that conducted in eastern Polynesia where West (2007) combined zooarchaeological relative abundance, demographic and isotope data on pig diet to demonstrate agricultural intensification. There are challenges, however, in combining these disparate datasets each with their own strengths and limitations.

Stable isotope studies arguably provide the most direct but non-specific evidence of dietary contributions. They are certainly providing direct evidence of the proportion of marine versus terrestrial components of human diet at prehistoric Pacific island sites (Bentley et al 2007; Field et al 2009; Jones and Quinn 2009; Kinaston 2010, Kinaston et al 2014a, 2014b; Leach et al 2000, 2003; Petchey et al 2014; Valentin et al 2010, 2014). At Teouma, stable isotope data indicates that Lapita diet was focused on marine resources and terrestrial plants, although there was a high variability of diet between individuals interpreted to be the result of a variety of reasons including population movement, as well as differences in gender specific diet and social status (Bentley et al 2007; Valentin et al 2010; Kinaston 2010; Kinaston et al 2014a).

However, these methods remain non-specific and thus provide only general indications of human palaeodiet on their own. Faunal and archaeobotanical studies complement

these by providing more details of specific biota exploited, but the limitations in terms of taphonomy, sampling issues and the lack of direct evidence for horticulture gained from faunal analysis can be daunting. Archaeobotanical studies are limited in quantifying the relative abundance of cultigens in deposits and typically provide a presence/absence of specific cultigens (Crowther 2005, 2009; Horrocks and Bedford 2005, 2010; Horrocks et al 2009; Horrocks and Nunn 2007; Kononenko 2007; Lentfer and Green 2004; Mathews and Gosden 1997). When combined these three methods without doubt provide a more robust and measured approach to subsistence studies.

## 2.5 Lapita foraging behaviour, resource depression, faunal extinctions and extirpations

### *2.5.1 Pre-Lapita fossil record*

Initially, because of the patchy faunal data and relatively depauperate modern biogeography in Island Melanesia and Remote Oceania, terrestrial island fauna were considered to be of little importance to Lapita foragers (Green 1979). Early biogeographical theory, while concerned with how biota dispersed throughout the Pacific, assumed that ecological equilibrium maintained a static diversity of species (MacArthur and Wilson 1967). However, considering the number of species extinctions, without replacement, that have occurred since the onset of human colonization this assumption is no longer valid.

In New Guinea and Island Melanesia the fossil record has indicated that pre-human mammal, bird and reptile diversity was greater before human arrival. These records now indicate extinct marsupial megafauna including a number of species of Kangaroo (*Protemnodon nombe, Protemnodon tumbuna*) and Diprotodontids (*Hulitherium, Maokopia, Zygomaturus*) were present as late as ca 35 ka in the New Guinea central highlands (Fairburn et al 2006). These megafauna fossil records may potentially overlap with early human settlement of the region (Field et al 2008; Hope et al 1993), although a direct human association has yet to be established (Long et al 2002; Fairburn et al 2006; Flannery 1995a; Flannery et al 1983; Menzies and Ballard 1994). Pre-Lapita human settlement of New Guinea appears to overlap with more recent extinctions of

smaller mammals during the mid-Holocene when settlement appears to have intensified, including a small wallaby (*Thylogale christensenii*) and the marsupial wolf (*Thylacinus cynocephalus*) (Hope and Hope 1976) and there is evidence of early human hunting in New Guinea at Nombe rock shelter from 25 ka onwards (Mountain 1993). The Island Melanesian fossil record is more limited and suggests that this region was relatively depauperate compared to New Guinea and lacking in megafauna (Flannery 1995b). A wide range of bat and rodent fauna, some of which have not been recorded historically, have been discovered primarily in New Ireland Pleistocene cave deposits (Flannery and White 1991).

Substantial paleontological research in the tropical southwest Pacific of Remote Oceania has played an important role in determining that the pre-human biogeographic distribution of terrestrial fauna was much more diverse. It is based on fossil deposits from limestone cave sites that revealed extinct endemic bird and reptile species in Fiji (Anderson et al 2001; Molnar et al 2002; Worthy 2000, 2004; Worthy et al 1999), Tonga (Pregill 1993; Pregill and Dye 1989; Steadman 1993b; 2006a), and New Caledonia (Anderson et al 2010; Balouet 1991; Balouet and Buffetaut 1987; Balouet and Olsen 1989) as well as extinct bat species in Tonga (Koopman and Steadman 1995). A diverse abundant Pleistocene and Holocene avifauna has been revealed, including the giant mega-fauna ratite *Sylviornis sp.* from New Caledonia (Anderson et al 2010; Balouet and Olsen 1989). Reptile megafauna has also been identified including giant iguana from Fiji (Molnar et al 2002; Worthy et al 1999), and giant Meiolaniid land turtles and dwarf land crocodile from Fiji (Worthy et al 1999) and New Caledonia (Balouet 1991; Balouet and Buffetaut 1987; Gaffney et al 1984). Unfortunately this pre-human biogeographical reconstruction has not been established for the Vanuatu archipelago. Cave sites with abundantly preserved pre-human paleontological fossil deposits have yet to be located despite recent attempts to locate such deposits during the 2006 Santo expedition when twenty caves were investigated (Alcover 2011; Wirrmann et al 2011b). A number of cave sites have been excavated on Malekula and Erromango (Bedford 2006a) but they returned only sparse late Holocene cultural and natural deposits.

### *2.5.2 Lapita marine exploitation*

Zooarchaeological research continues to point towards a great abundance of fish and shellfish remains from Lapita archaeological sites in both Near and Remote Oceania (Anderson 2008; Bedford 2006a; Best 1984, 2002; Burley 1999; Clark and Szabo 2009; Densmore 2010; Green 1986; Kirch 1988; Kirch and Dye 1979; Kirch and Yen 1982; Kirch et al 1991; Sand 2010; Summerhayes et al 2010; Swadling 1986). This has led to a general acceptance that Lapita foraging behaviour was focused on marine resources and preconditioned to adapt to various tropical marine environments encountered during the course of Oceanic colonization (Butler 1988, 1994; Clark and Szabo 2009; Davidson et al 2002; Dye and Steadman 1990; Green 1979, 1986; Ono 2003; Walter 1989). This extensive array of data across the whole Lapita expansion has even encouraged studies of geographical variation in inferred Lapita fishing behaviour from faunal data (Allen 2002; Butler 1994; Clarke and Szabo 2009; Ono 2003). Indications are that Lapita peoples used a range of capture techniques that allowed specialized focus of exploitation on the most abundant fish taxa present in various local marine environments accounting for variation in Lapita fish assemblages.

In Remote Oceania, studies have also established that sea turtles were heavily exploited during early Lapita colonization compared to later periods of settlement (Allen 2007; Best 2002; Kirch and Yen 1982; Dye and Steadman 1990). In some regions they are considered chronological markers for early colonizing sites (Burley 1999; Sand et al 2000). Isotope studies have also supported instances of significant Lapita marine diet in Near Oceania at Watom (Leach et al 2000; 2003; Shaw et al 2008), and Remote Oceania at Teouma (Bentley et al 2007; Kinaston et al 2014a; Valentin et al 2010).

### *2.5.3 Lapita terrestrial exploitation*

A substantially growing body of zooarchaeological analysis, conducted mostly by palaeontologists, from Lapita sites in Oceania has established the potential importance of a variety of terrestrial ecologies to Lapita subsistence. These studies have revealed the impact of Lapita settlement on a diverse variety of small bodied local naïve avifauna and large bodied reptilian mega-fauna, resulting in a number of regionalized extinctions

and extirpations (Bedford 2006a; Burley1999; Irwin et al 2011; Mead et al 2002; Steadman 1995, 1999b, 2006a; Steadman et al 1990, 2002a, 2002b; Summerhayes et al 2009; Worthy and Clark 2009). In Near Oceania the evidence is not so strong, although a diverse range of rats and small marsupials were exploited by Lapita settlers in New Guinea (McNiven et al 2012). Pre-Lapita and Lapita impacts on terrestrial island ecologies in Near Oceania appear to have been less dramatic, probably because of millennia of human occupation and co-evolution of avifauna with invasive mammals (Steadman 2006a; Summerhayes et al 2009), with a more limited range of extinct bird species present in Lapita sites on the islands of Mussau and New Ireland in the Bismarck's (Steadman and Kirch 1998; Steadman et al 1999). The evidence for human associated mega-fauna exploitation in Lapita deposits is limited in Near Oceania to a few crocodile bones at Telepakemalai on Mussau (Kirch et al 1991). There is certainly no evidence as yet of mega-fauna extinctions in Island Melanesia (Flannery 1995b). Pre-Lapita Pleistocene extinctions remain poorly understood despite good faunal sequences from a few Pleistocene caves (Spriggs 1997; White et al 1991). Identifying naïve fauna driven to extinction will undoubtedly require the location and excavation of the earliest human occupations during the initial Pleistocene colonising phase. This is a much greater challenge than finding more highly visible sites associated with Lapita emergence during the late Holocene.

In Remote Oceania, accounts of rapid ecological destruction, with the extinction and extirpation of many defenceless land and sea bird species from the archaeological record soon after human arrival, has been established in Tonga (Steadman 1993b, 1995, 2006a; Steadman et al 2002b), Fiji (Irwin et al 2011; Worthy and Clarke 2009), Tikopia (Steadman et al 1990) and Ofu, American Samoa (Steadman 1993a). This pattern of avifaunal extinction of endemic land birds and localized extirpation of sea bird nesting colonies continued soon after sustained migrations of ancestral Polynesians into eastern Polynesia (Steadman 1989, 1995; Worthy and Boult 2011), Hawaii (Athens et al 2002; Olson and James 1984), and New Zealand (Oskam et al 2012). Mass extinctions on Pacific Islands of large numbers of native land bird species is estimated by Steadman (1995, 2006a) to be between 50-90% (mostly endemic flightless rails and megapodes). Recently in New Caledonia, archaeological efforts to link *Sylviornis sp* a large megafaunal ratite bird species in association with early human settlement in the Pindai caves were unsuccessful due to the difficulty with provenance in a mixed cultural

context, although direct dating of these bones at 3000 BP gave an overlap with human arrival (Anderson et al 2010).

Given Vanuatu's location at the junction between three routes of faunal immigration and the documentation of the dramatic impact on insular endemic bird species elsewhere soon after human arrival, it is most likely that the Lapita people had a similar impact on Vanuatu prehistoric avifauna. However, prior to this project, only small quantities of a few species of extinct birds had been identified from very late-Lapita and immediately Post-Lapita sites in Vanuatu, a sign that the earliest and well-preserved Lapita sites had yet to be identified and sampled (Bedford 2006a, Steadman 2006a). Extinct avifauna identified to date, include a new species of parrot *Eclectus infectus* (related to *E. roratus* in the Solomon Islands) (Steadman 2006b), identified from a few bones from archaeological and paleontological sites in Tonga and the Late-Lapita archaeological site of Malua Bay on the Northwest coast of Malekula, Vanuatu. Also from the Malua Bay site, an extinct flightless rail *Porzana undescribed sp. A* was identified. At the immediately post-Lapita Arapus site on the west coast of Efate, the Brown Goshawk *Accipiter cf. fasciatus* was identified and has since became locally extirpated (Bedford 2006a; Steadman 2006a). A new species of megapode *Megapodius undescribed sp.* and *Aplonis undescribed sp.* was found at the immediately Post-Lapita site of Ponamla on Erromango (Bedford 2006a; Steadman 2006a). *Gallirallus undescribed sp. C* was also identified from Toga Island in the Torres Group, northern Vanuatu (Steadman 2006a). Three sea bird bones represent extirpated shearwater and booby species from Malekula, Erromango and Efate (Steadman 2006a). Analysis of faunal assemblages from earlier Lapita periods of settlement in this region is expected to increase this number significantly and provide a fuller picture of ecological biodiversity during this period.

The other most common small bodied terrestrial vertebrates exploited by Pacific Island communities since Lapita arrival were fruit bats. Historically fruit bat populations have been under pressure from southeast Pacific hunting using improved hunting methods (guns) combined with increasing habitat loss (Brooke and Tschapka 2002; Hand and Grant-Mackie 2012; Helgen and Flannery 2002; Helgen et al 2009). Their documentation in early colonizing faunal assemblages, however, has been very patchy but there have been a few in-depth studies on late or immediately Post-Lapita fruit bat assemblages in Vanuatu at the Arapus and Ponamla sites (see Bedford 2006a;

MacDonald 2002). Based on much more significant fruit bat vertebrate quantities from these sites, MacDonald (2002) argued that fruit bats have played a more significant role in subsistence behaviour in Vanuatu than elsewhere in the Pacific but this could also be the result of differences in sampling, recovery and recording. Otherwise very little is known about fruit bat exploitation during the Lapita/Post-Lapita transition or about human associated bat extinctions. Scattered research using archaeofauna, palaeofauna, and historic museum collections indicates that a few fruit bat extinctions occurred in New Caledonia and Polynesia sometime after initial prehistoric colonization and also again soon after European arrival (Helgen et al 2009; Koopman and Steadman 1995). The pre-human bat fauna of Southeast Melanesia including Fiji, New Caledonia, Reef Santa Cruz and Vanuatu are largely unknown, but given the numbers of bat bones found in early sites in Vanuatu (Bedford 2006a, MacDonald 2002), Tikopia (Kirch and Yen 1982), and Fiji (Best 1984; Worthy and Clark 2009) it is highly likely that a number of fruit bat species disappeared from these islands during the course of human settlement.

Outside of Vanuatu, extinct terrestrial reptile mega-fauna exploited by Lapita colonists include a large bodied giant iguanid in Fiji (Irwin et al 2011) and Tonga (Pregill 1993; Pregill and Dye 1989; Steadman 2006a; Steadman et al 2002a). From Tonga in particular several hundred (NISP=1321) of these extinct giant iguana bones have now been recovered from a number of Lapita sites in Ha'apai (Pregill and Steadman 2004). Dwarf crocodile has also been found in New Caledonian Lapita sites (Balouet 1991; Balouet and Buffetaut 1987), although details of Lapita association are vague. They have also been found at Naigani in Fiji (Irwin et al 2011). Meiolaniid giant turtle remains were reported in Lapita sites in the Loyalty Islands but without detail of site location or cultural association (Balouet 1991: 1388). Recent research has demonstrated the interaction of Lapita with now extinct reptile mega-fauna in Vanuatu. On Efate, a dwarf land crocodilian species *Mekosuchus kalpokasi* was identified from the immediately Post-Lapita Arapus site (Mead et al 2002) and Meiolaniid (*?Meiolania damelipi*) giant tortoise remains were recently discovered from the Teouma Lapita site (White et al 2010) as part of this project (see Chapter 3).

### *2.5.4 Lapita resource depression*

The decline in abundance of now extinct/extirpated fauna in immediately Post-Lapita deposits, and the disappearance of bird and reptile species in island groups within Remote Oceania sometime after Lapita arrival, has led to arguments for Lapita overkill, or 'blitzkrieg' causing faunal devastation as a result of concentrated human predation (e.g. Bedford 2006a; Burley 1999; Steadman 1999a; Steadman et al 2002b). This has provided very strong but circumstantial evidence for Lapita terrestrial ecological impact. The use of the overkill model to explain extinctions has been challenged not just in Lapita archaeology but also other regions around the globe from earlier time periods. This is essentially due to the lack of direct evidence or because of the difficulties in distinguishing human predation from other factors including climate change (Nagaoka 2012; Seeto et al 2012).

The effects of other human related activities, including deforestation from agriculture resulting in habitat reduction and Lapita introduced mammalian predators, have also been proposed as likely contributors to terrestrial ecological tipping points (Prebble and Wilmshurst 2009; Steadman 2006a). Nagaoka (2012) has recently argued for the importance of demonstrating direct associations between human hunting and mega-fauna depletions and extinctions to test the overkill model using prey demographic studies. Such studies have yet to be carried out on Lapita period terrestrial fauna, although they have been carried out on Lapita and immediately Post-Lapita shellfish assemblages from the Reef Santa Cruz (Swadling 1986), Vanuatu (Bedford 2006a; Gyngell 1997), New Caledonia (Sand et al 2000), Fiji (Heorake 2009; Szabo and Clark 2009; Seeto et al 2012) and Tongan Lapita sites (Spennemann 1987). Such studies have demonstrated the reduction in shellfish sizes over time as well as the decline and or extirpation of large shell species which are clearly indicators of direct human predation. Arguments of localized shellfish extirpation as a result of shoreline retreat from declining sea levels as advocated by some (Seeto et al 2012; Spennemann 1987) are less convincing considering the number of sea level events over hundreds of millennia that have not been associated with species extinctions. Given that understanding Lapita impacts on the terrestrial ecology is crucial to understanding and explaining Post-Lapita subsistence change, more needs to be done to address this lack of direct association of extinctions with human impacts on terrestrial fauna.

## 2.6 Lapita transported landscapes and modified terrestrial environments

There is evidence for early independent agricultural development in New Guinea as evidenced by results at Kuk swamp in the highlands after 10000 BP (Denham et al 2004). But in neighbouring Island Melanesia pre-Lapita people are considered to have been low intensity hunter gatherers since 45-35 ka BP who practiced non-intensive arboriculture as early as 25000 BP (Latinis 2000: Table 1; Spriggs 1997), adapting to tropical island rain forests without the use of domesticated animals or plants (Allen 1996; Torrence et al 2004). Latinis (2000) argues for at least some partial continuity of arboriculture in the region before and after Lapita arrival, at the same time conceding the difficulty of distinguishing between agriculture, horticulture and arboriculture economic systems. The association of the introduction of a distinct transported package of fully domesticated tree and root plants into Island Melanesia with the arrival of Lapita in the Bismarck's during the late Holocene has therefore been questioned (O'Connor et al 2011; Spriggs 1997; Specht et al 2014).

### *2.6.1 Horticulture evidence*

The evidence for Lapita transported economies has increased over the past few decades, but whether Lapita economies developed this during assimilation within the wider Near Oceanic region or transported these as a package from ISEA remains a contentious issue. The picture is likely to be more complex and involve a combination of both processes. Direct evidence for Lapita use of domesticated crops in the Bismarck's comes from archaeobotanical remains from the Talepakemalai Lapita site in the Mussau Islands (Kirch 1989), in the Arawe Islands (Mathews and Gosden 1997), and the SAC site on Watom Island (Lentfer and Green 2004) as well as from starch residue analysis on artefacts from various Lapita sites in the region at Kamgot (Crowther 2005, 2009) and New Ireland in general (Kononenko 2007). This evidence clearly supports that the Lapita people used a range of domesticated Melanesian tree plants including coconut, canarium almond, Vi apple, and Tahitian chestnuts (Kirch 1989), as well as domesticated forms of taro, banana and yam (Crowther 2005; Lentfer and Green 2004;

Mathews and Gosden 1997). However, some of these species were extant in the region before Lapita arrival and do not relate to the concept of transported landscapes.

Recently, evidence of microfossil domesticated plant remains including banana, Araceae and unidentified taro and yam species have been found in Lapita sites in Remote Oceania at Uripiv Island (Horrocks and Bedford 2005) and Vao Island in Vanuatu (Horrocks and Bedford 2009, 2010), and at Bourewa in Fiji (Horrocks and Nunn 2007). These are significant finds and indicate for the first time unequivocal direct evidence of the mixed Lapita economy in Remote Oceania as it dispersed from Near Oceania. These studies, however, cannot provide quantified evidence of how much these crops contributed to Lapita diet compared to other dietary components during the colonization process, rather they provide only an indication of presence/absence of certain species. In essence they do not provide a detailed account of the transition to economies structured towards horticultural food production. Direct stable isotope analysis appears more suited to this task and such analysis on human skeletons at the late Lapita site at Watom on New Ireland in the Bismarck's showed the Lapita and Post-Lapita diet consisted mostly of plant food but with a significant marine component (Leach et al 2000). Similar studies have found a similar pattern in Remote Oceania, at the Teouma and Uripiv Lapita sites in Vanuatu (Bentley et al 2007; Kinaston et al2014a, 2014b; Valentin et al 2010).

### *2.6.2 Introduced domesticated and commensal animals*

Island Melanesia was relatively more depauperate than New Guinea in terms of faunal diversity and Pleistocene foragers responded to the lack of terrestrial animals by introducing New Guinean marsupials which became the most commonly hunted terrestrial fauna in the Bismarck's during the late Pleistocene (Leavesley 2005). Much later, Lapita people brought with them domesticated and commensal mammals (domestic pigs *Sus scrofa*, rats *Rattus exulans* and possibly dogs *Canis familiaris*) and chickens transported from somewhere in mainland Southeast Asia or ISEA according to MtDNA evidence from pig and rat bones (Lum et al 2006, Larson 2007, Matisoo-Smith 2009). These Lapita commensal introductions are considered the first of their kind to the New Guinea region (O'Connor et al 2011; Spriggs 1997), although the evidence of

Lapita introductions of dogs and pigs has been challenged and a possible alternative late or Post-Lapita introduction has been proposed (Specht and et al 2014).

Pigs, when managed are considered proxies for agriculture because of their domesticated status as they are hand fed agricultural produce in many New Guinea and Pacific Island cultures and are considered integral components within horticultural systems for sedentary settlements (see Hide 2003; Rappaport 1968; West 2007). It has been argued that large amounts of domesticated crops are required to feed both humans and pigs leading to competition for vegetable resources (Kirch 2000; Green and Anson 2000). The evidence for Lapita pig introductions and management across Oceania has been rather patchy (see Anderson 2009; Specht et al 2014) and limited to a few ambiguous instances in Island Melanesia at early Lapita sites such as Kamgot in the Arawe Islands (Summerhayes and Allen 2007), Mussau Island sites (Egloff 1975; Kirch 1987; Kirch et al 1991), and the later partially disturbed late Lapita site at Watom (Green and Anson 2000; Smith 2000). Of these sites, only the deposits of Watom Island returned significant amounts of pig remains. It was demonstrated using age profile data that pigs at Watom were managed rather than hunted (Smith 2000).The oldest reliable date for pig in the New Guinea-Archipelago region was from a single tooth from Watom dated to 2760-2547 cal BP (Athfield et al. 2008). The earliest date for mainland pigs in New Guinea is at Caution Bay dated to 2500-2350 cal BP (McNiven et al 2012).

The case for pig husbandry during the Lapita expansion east into Remote Oceania has remained largely unresolved. Small amounts of pig bone and a pig tooth artefact were found at the Lapita sites RF-2 and RF-6 in the Reef Santa Cruz Islands (Green 1976). At Tikopia, which appears to date to the end of the Lapita period, a few pig bones were found associated with the Kiki phase 2900-2100 BP (Kirch and Yen 1982). Pig bone has yet to be recorded from New Caledonia Lapita sites (Sand 2010), while in Fiji pig bone has been recorded from disturbed contexts that probably post-date Lapita (Best 1984; Nunn et al 2007; Worthy and Clarke 2009). None of the pig bones are securely dated to before the last 1000 years (Clark and Anderson 2009). A pig bone reported from the Yanuca site and used to infer Lapita agricultural introduction into the region during the 1980s (Hunt 1980, 1981), has in a further twist since been re-identified first as turtle by Worthy and Gaffney (Worthy and Clarke 2009: Figure 115) and more recently as land turtle (Hawkins unpublished data). In Tonga claims of pig bone at Lapita sites on Tongatapu (Poulsen 1967) and Niuatoputapu (Kirch 1988) have since

had their contexts questioned by Anderson (2009), while Burley (1999) reports no pig bone from early Lapita sites in the Ha'apai group of Tonga.

Small quantities of pig bone have been identified from Vanuatu Lapita contexts including the Lapita site of Ifo on Erromango and the late Lapita site at Malua Bay on Malekula, as well as immediately post-Lapita contexts at Ponamla on Erromango and Arapus on Efate from 2900 BP onwards (Bedford 2006a). Substantial numbers of pig bones have also been reported, although un-quantified, from a number of Lapita sites including those on the small islands of northeast Malekula (Bedford 2007), on Malo (Hedricks n.d., 1971) at the Erueti site on Efate, which included a disturbed Lapita component (Garanger 1972) and by Galipaud and Kelly (2007) at Makué on Aore Island. Future publication of these results could substantially increase what we know about Lapita behaviour in relation to the establishment of pig management systems.

Dog remains associated with Lapita era deposits is much rarer and more contentious with sporadic dog bones present at Near Oceanic Lapita sites at Talepakemalai in the Mussau Islands (Kirch 1987; Kirch et al 1991), on Apalo in the Arawe Islands (Gosden et al 1989), and at the Kamgot site in the Anir Islands (Summerhayes and Allen 2007). The earliest reliable directly dated dog bones are from Caution Bay 2500-2350 cal BP (McNiven et al 2012) and from Post-Lapita deposits on Buka Island 1900 cal BP in the Solomon Islands (Flannery et al 1988). Dogs do not appear in the archaeological record, however, until much later in Remote Oceania archaeological sites (Anderson 2009).

Storey et al (2008) argue that while chicken had a widespread distribution in Lapita sites in Remote Oceania they were largely absent from early Lapita levels in Near Oceania Lapita sites. However, small amounts of chicken remains have been reported in association with Lapita deposits at Mussau (Steadman and Kirch 1998) and disturbed deposits at Watom (Storey et al 2008) so this discrepancy is just as likely to represent a sampling and preservation problem.

The Pacific rat *Rattus exulans* also dispersed with Lapita people throughout the entire Lapita distribution, while the New Guinea Spiny rat *Rattus praetor* originally from New Guinea appears to have been distributed with Lapita as far as Fiji, although it has been found in only immediately Post-Lapita or late Lapita deposits in Vanuatu to date (White et al 2000).

In summary the uncertainty around the timing of the introduction of domestic animals during the Lapita expansion, demonstrated by the patchy zooarchaeological record across the Lapita distribution, has raised the possibility that early Lapita colonists were initially not reliant on a complete introduced agricultural "package" for their subsistence (Anderson 2009; Bedford 2006a; Burley 1998; Burley and Connaughton 2007; Clark and Anderson 2001; Kennett et al 2006; Specht et al 2014).

### *2.6.3 Terrestrial environmental modification in the Pacific during the Lapita period*

As a result of perceived intensive horticultural practices, prehistoric humans have been held responsible for modifying tropical New Guinea and Pacific Island terrestrial environments that are considered susceptible to rapid degradation from human activities (Enright and Gosden 1992; Haberle et al 2012; Kirch and Hunt 1997; Spriggs 1997). The paleoenvironmental data is limited and patchy but there is significant evidence for the impact of pre-Lapita people in Near Oceania and Lapita people in Near and Remote Oceania.

In the New Guinea highlands, human induced environmental changes are quite visible during the terminal Pleistocene, (Fairbairn et al. 2006; Haberle 1994; Hope and Golson 1995). By the early Holocene this had accelerated (Haberle et al 1991), probably as a result of population increase and the establishment of agriculture in New Guinea around this time (Denham et al 2004). However, while the impact that pre-Lapita people had on Island Melanesian island environments remains largely unknown, there is some limited evidence of environmental disturbances prior to the Lapita period (Enright and Gosden 1992).

Research suggests that Lapita occupation and pioneering slash and burn horticulture resulted in much more dramatic environmental change in Island Melanesia compared to pre-Lapita periods (Summerhayes et al 2009; Haberle 1994). Environment change appears more dramatic in Remote Oceania, possibly as a result of greater archaeological resolution for initial colonisation (Summerhayes et al 2009), although Haberle (1994) has demonstrated disturbances in the Solomon Islands during the late Holocene.

Paleoenvironmental studies focusing on inland swamps have demonstrated that the arrival of Lapita colonists on previously uninhabited Pacific islands in Remote Oceania coincided with the onset of significantly disturbed vegetation, dramatically increased charcoal records and higher rates of soil erosion resulting in the infilling of valleys, bays and lagoons. This is assumed to be the result of swidden slash and burn related forest clearance as demonstrated in New Caledonia (Stevenson 1997), Vanuatu (Hope and Spriggs 1982; Hope et al 1999; Wirrmann et al 2011a), and Fiji (Hope et al 2009). Spriggs (1986) argues ultimately that while destructive to the environment and ecological habitats, in some cases human induced erosion often created rich alluvial coastal terraces that were more productive for horticulture and more advantageous to long-term human settlement.

## 2.7 Summary

A review of the literature has identified a number of gaps in our knowledge relating to Lapita subsistence and the change which occurred during the Post-Lapita transition. More specifically, interactions with island ecologies and human induced resource depression, while directly understood for molluscs is not explicitly linked to terrestrial vertebrate fauna. The idea of the introduction of complete packages of transported landscapes by Lapita from ISEA reduce what is actually likely to have been a more complex and varied series of introductions and localized developments in the Asia-Pacific region. The identification of transitions from broad spectrum foraging to the establishment of food production systems are also vague and trying to make the evidence fit to linear developments of increasing food production in response to resource depression may be too simplistic. Lapita subsistence adaptations have been broadly identified using a range of stable isotopic, archaeobotanical, and archaeofauna studies but it appears that Lapita subsistence behaviour was more complex and varied over time and space than previously thought. The literature reviewed here suggests that Lapita subsistence behaviours varied from New Guinea to western Polynesia depending on differences in ecology, colonization history and cultural practices from west to east. But these patterns remain general. Lapita socio- economic systems are likely to have been more fluid and constantly changing over time across the full geographical extent of its expansion.

A fuller understanding of Lapita subsistence economies and how they changed over time is also still hostage to a range of inherent problems including limited datasets as a result of mixed archaeological contexts, poorly refined chronologies and a paucity of preserved abundant vertebrate samples and limited analytical methodologies. These limitations have combined with culture historical colonization models, linked to historical ecological methods, to reduce what was potentially a dynamic and fluid adaptive Lapita culture to static archaeological records, typically altered post-deposition and one size fits all subsistence packages. The development of quantified models underpinned by robust theoretical frameworks using more detailed methods with adequate faunal samples is required. Once these issues are overcome then these gaps in our understanding of Lapita subsistence and how it changed will eventually improve. Once robust multivariate datasets become available we are likely to start to see a greater complexity and variation in Lapita subsistence behaviours over time as a result of regional and temporal diversity in ecological and cultural conditions.

This study attempts to overcome many of the issues identified in this chapter. The abundant well preserved and stratified faunal remains, recovered using fine grained recovery methods from the Teouma Lapita site, make such a more detailed and quantified study of Lapita subsistence change possible. The following chapters first outline the Teouma site, fieldwork and vertebrate assemblages. A Human Behavioural Ecology (HBE) framework, combining OFM and costly signalling, is used in this thesis to explain Lapita subsistence change at Teouma. These models were used to generate predictions of prehistoric human subsistence behaviour which were then tested using multiple lines of zooarchaeological evidence.

# 3 Teouma: Excavations, Analytic Temporal Units, Recovery Methods and Vertebrate Assemblages

In this chapter, six sections focus on the Teouma site, excavation results, chronology, temporal units, recovery methods and vertebrate assemblages. The Teouma site section describes the site location and archaeological background that forms the backdrop for ecological and cultural interpretations. In the excavation section the excavation results of the six field seasons at Teouma from 2004-2006 and 2008-2010 are summarized and include details of the excavation methodology, provenance units and chronology. The analytic temporal unit section describes the analytical spatio-temporal framework used to develop the diachronic sequence from which temporal changes in subsistence patterns could be investigated. The recovery methods section details the disparate methods used to recover materials from archaeological deposits and tests their validity using statistical analysis. The vertebrate remains recovered during the Teouma excavations are then outlined based on provenance unit associations with descriptions of the ecological contexts and biological information of identified taxa.

## 3.1 The Teouma site

The Teouma Lapita site is located at Teouma Bay, a small sheltered harbour on the south coast of the central Vanuatu island of Efate (Figure 3-1 and 3-2), where diverse ecological conditions present today would have been most favourable for settlement on the island during prehistory (see Chapter 2). The sheltered Teouma harbour is ideal for fishing for pelagic and reef fish species that come into the harbour. Adjacent to the site are mangrove and wetland environments with streams supplying fresh water that stretch into a substantial inland terrestrial environment. This terrestrial hinterland would have been a significant landscape for terrestrial resource patch foraging and swidden agriculture.

When the Lapita occupation began around 3000 BP the site was adjacent to the coastline at the harbours western edge on a small headland adjacent to a river. However, a combination of continuous tectonic uplift since the Pleistocene combined with sea level fall during the mid to late Holocene has resulted in prograding shorelines and

upraised beach terraces throughout many islands in the Vanuatu Archipelago (Cabioch and Ayliffe 2001; Cabioch et al 2003; Neef and Veeh 1977; Neef et al 2003; Pineda and Galipaud 1998; Taylor et al 1987). Tectonic uplift has caused the raised limestone terrace platforms that punctuate Efate's landscape to great elevations including the limestone cliff at the south edge of the Teouma Lapita site (Neef and Veeh 1977, Lecolle et al 1990). On Efate the most recent upraised terrace during the late Holocene is now a low continuous coastal platform 1.5 m above high tide level (Bloom et al 1978). The Teouma site is now situated on this ancient upraised coral reef edge some eight meters above sea level. Tectonic uplift in combination with sediment infilling has resulted in the site now being 800 meters to the northeast of the current Teouma Bay harbour edge (Bedford et al 2006, 2007).

Currently situated in a cattle farm within a decaying coconut plantation, the Teouma site was accidentally discovered during the mining of soil for the construction of a prawn farm in October 2003 (Bedford et al 2004). This resulted in the disturbance in the northern part of the site by bulldozer and backhoe cuts which truncated much of the upper midden deposits leaving loose mixed deposits. The remaining lower deposits in the northern area and whole surrounding areas to the south east and west remained intact and undisturbed (Bedford et al 2006).

The Lapita site at Teouma is considered one of the earliest human settlements in Vanuatu (Bedford and Spriggs 2007). Although it is slightly later than Lapita settlement at Makue based on radiocarbon determinations, Teouma appears to be an initial colonising settlement on Efate Island. More significantly Teouma is the earliest cemetery in the Pacific (Bedford et al 2006) with the largest concentration of Lapita burials numbering almost 100 individuals (Bedford et al 2010). The cemetery provides an unprecedented opportunity to learn about the Lapita people themselves directly; from their broad diet using isotopes, to their ritual behaviour in the treatment of the dead, their general health and disease, along with general demographic information. The pottery from Teouma is also significant in terms of its continuing contribution to the understanding of what we know about ceramic sequences, vessel forms and styles of the Lapita cultural horizon. The dentate-stamped pottery is varied with some similarities of designs from the earliest period of site occupation with New Caledonia, Reef Santa Cruz and further west in the Bismarck's, but it also includes vessel decoration and forms unique to Teouma (Bedford et al 2006, Bedford and Spriggs 2007). Obsidian

sourced from the Bismarck's strongly supports an early arrival and founding Lapita settlement at Teouma (Bedford et al 2006; Reepmeyer et al 2010).

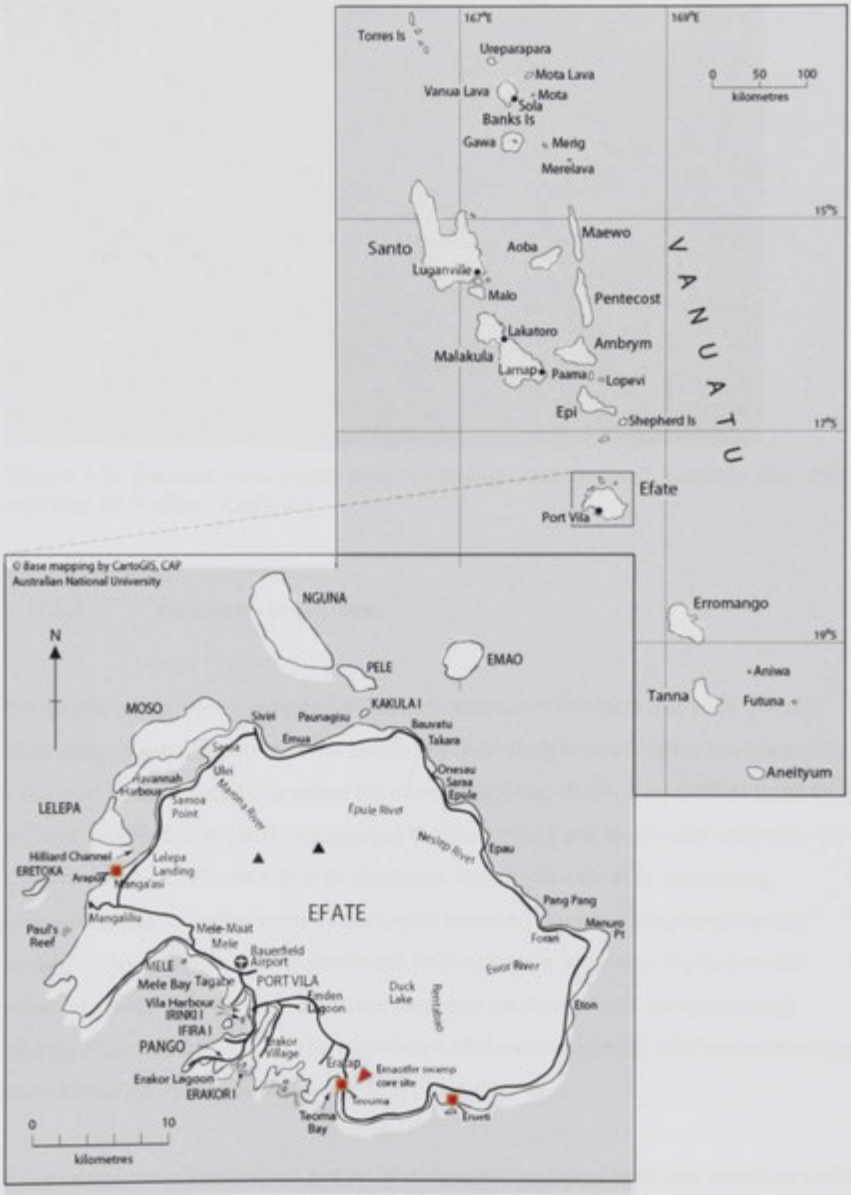


**Figure 3-1: Teouma site location**

**Figure 3-2: Teouma excavations (centre) facing south towards Teouma Bay. Photo courtesy of Wallace Ambrose.**

## 3.2 Teouma excavations

Six field seasons were conducted at Teouma between 2004-2006 and 2008-2010 consisting of approximately seven months of field work in total. These have been described in some detail elsewhere (Bedford et al 2004, Bedford et al 2006; Bedford et al 2009, Bedford et al 2010; Spriggs and Bedford 2013) and key details need only be summarized here. The first five field seasons were instrumental in identifying, excavating and recording most of the Lapita cemetery area and the post-cemetery midden deposits above it. The final sixth field season in 2010 was focused on the adjacent Lapita midden area, contemporary with the cemetery at its eastern edge (Spriggs and Bedford 2013). The knowledge of the site increased with each excavation and excavation strategies and methods evolved over time.

Excavations were focused not just on recording all aspects of mortuary practices within the cemetery but also on recovering adequate samples of material cultural from which to better understand aspects of Lapita culture and economy and how this related to the cemetery and socio-economic aspects of settlement over time. The excavations initially assessed the extent of the damage to the site by the prawn farm related earthworks that

mined the tephra-rich black soil. It was discovered that much of the northern part of the site had been truncated. The disturbed deposits were identified and removed and the remaining deposits were found to be largely *in situ* especially the lower Layer 3 deposits and much of the lower part of Layer 2. Much of the early excavations also focused on finding the extent of the site, the site layout and defining the stratigraphy and nature of cultural deposits. Once this was achieved larger excavations were focused on discrete activity areas such as the cemetery and midden areas.

The excavation methods were targeted at providing the greatest amount of information with the time and resources available but also in a manner that provided a great level of spatio-temporal resolution. The topsoil Layer 1 was usually removed quickly by spade within coarse spatial units of general north, south, west and east 2x2m units as this layer had proved to have very sparse cultural material largely relating to a period of natural accumulation primarily through volcanic tephra deposits. Field excavation of the denser cultural deposits in Layer 2 and 3 was conducted carefully by hand using trowels in 1x1 m squares within a grid system, excavating down by stratigraphic layer and 20 and 10cm spits. Pottery discovered *in-situ* within the cemetery (Layer 3) was recorded in three dimensions using a total station to achieve fine grained recording. The excavation units, site topography, and excavation squares were also recorded in this manner to produce an accurate topographic site map. Materials recovered included bone, shell, pottery, and worked stone from all deposits including those that were spatio-temporally distinct as well as from disturbed deposits. All materials were entered into a level sheet with field sample numbers relating them to their spatio-temporal contexts.

These field seasons have contributed to a large areal excavation which is rare in the Pacific. Teouma is one of the largest Lapita archaeological excavations undertaken to date comprising a total main excavation area of 473m$^2$. This was focused on the cemetery area encompassing a 10-15m by 30-40m area (Areas 2, 3a, 3b, 3bext, quarry extension) approximately 353 m$^2$ in total. The site has spatio-temporally distinct areas and deposits in relation to the cemetery, including a contemporary Lapita midden immediately adjacent on the eastern margin of the cemetery (Area 2ext), and post-cemetery midden contexts overlying the cemetery areas. Much of the upper deposits in the northern half of Area 2 and Area 3b (both excavated in 2004-2006) were discovered to have suffered the most disturbance from mechanical excavation. Surrounding these areas, where settlement was concentrated, a range of test pits and trenches determined

the extent of the site (see Figure 3.3 for a site plan). These included Area 7c (not included in this study) situated some 100 meters to the south of the main cemetery/settlement area at Teouma where some later burials and ephemeral Lapita and more concentrated Erueti midden was uncovered.

## 3.3 Chronology and settlement

The chronology and settlement of the Teouma site, described in this section, is based on stratigraphic records outlined below, radiocarbon dates outlined in Petchey et al (2014) and preliminary ceramic analyses summarized in Spriggs and Bedford (2013). The period of Lapita and Post-Lapita prehistory of Teouma can be seen in the excavation plan (Fig 3-3) and two stratigraphic section drawings (Section 1, Figure 3-4; Section 2, Figure 3-5). Three basic stratigraphic layers cover the entire Teouma site. These include the bottom underlying natural orange tephra (Layer 3; Unit D) upon which settlement began, an anthropogenic midden deposition (Layer 2; Units B2-B1) and a topsoil (Layer 1; Unit A) representing natural post-settlement deposition of the last few thousand years. Section 1 (Figure 3-4) was taken through the cemetery area from north to south. It demonstrates the natural orange tephra (overlying the upraised ancient reef) upon which the Lapita settlement commenced and into which burials were deposited. A build-up of post cemetery midden (Layer 2) over the top of Layer 3 occurred once the cemetery was no longer in use. Section 2 (Figure 3-5) was taken from the eastern baulk in the adjacent Lapita midden area, also the north to south axis, and shows the three layers of Lapita midden (C3-C1). This midden, based on preliminary ceramic analyses and radiocarbon dates (Spriggs and Bedford 2013), appears to be contemporary with the adjacent cemetery.

The radiocarbon dates taken from a variety of materials at Teouma provide a broad outline of absolute chronology. The rates of cultural deposition and change in material culture appear to be much more rapid than absolute dating currently provides, with sharply defined chronological units both horizontally and vertically. Radiocarbon dates from all deposits range between 2960-2660 cal BP with some inversions likely to be the result of post-cemetery occupation disturbances (Petchey et al 2014). Currently absolute dating may be unable to give the temporal resolution needed to be able to say with certainty the absolute time depth represented by distinct temporal deposits at Teouma.

Petchey et al (2014) in a summary of AMS dates on 36 human burials and five Conus sp. burial associated artefacts (in combination with a Bayesian statistical analysis) indicate that the cemetery was in use between c. 2940-2710 cal BP, representing roughly 150-240 years of funerary rites within the cemetery. In addition 38 direct AMS dates on terrestrial animal bones (pig, tortoise, chicken), marine shell and nut charcoal, from the Lapita cemetery and Lapita midden areas, supports the ceramics evidence indicating some contemporaneity between the Lapita cemetery and the adjacent Lapita midden, and probably between the Lapita midden and the Lapita post-cemetery (B2) midden deposits (Petchey et al 2014). The post-cemetery midden units (B2-B1) are currently undefined in absolute years but span the Late-Lapita to Early Erueti ceramics phase which terminates ca. 2500 BP (Bedford 2006a).

Based on stratigraphic data and the horizontal and vertical deposition of material culture, Teouma settlement can be organized into three broad phases of occupation. The earliest phase consists of two spatio-temporal components, the Lapita cemetery (Unit D) and adjacent contemporary Lapita midden period (Units C3-C1). The second phase consists of a later Lapita midden (Unit B2) that overlies and post-dates the cemetery and a third overlying Erueti midden (Unit B1) phase. They represent overlapping time periods spatially as represented on the plan (Figure 3-3). Based on these data the chronology of Teouma is described below in greater detail.

### *3.3.1 Lapita cemetery and midden period (2960-2710 cal BP)*

Initially, Lapita settlement was focused on the cemetery at the edge of the upraised reef and these early deposits were between 20-60cm deep concentrated in and on the natural orange tephra (Layer 3; Unit D) deposited in lagged reef surfaces. Elaborate Lapita decorated pottery was recovered in direct association within and around the Lapita burials and in some cases bones were placed inside vessels, very reminiscent of burial practices found in Island Southeast Asia (Bedford et al 2006, 2007; Spriggs and Bedford 2013).

The adjacent Lapita midden in Area 2ext appears to have been a rapid deposit of concentrated midden beginning on and within the natural Layer 3 orange tephra (C3). A

dark anthropogenic soil (Layer 2) (C2) rapidly developed over Layer 3, mixed with coral cobbles and dense shell matrix 20-50cm thick depending on the slope of the reef edge from south to north. Plain and incised wares were found within this concentrated midden (consisting of shell and bone) with no burials (Spriggs and Bedford 2013), an indication of everyday living in close proximity to ritualized funerary rites being practiced in the contemporary adjacent cemetery. The two midden layers Layer 3 (C3) and Layer 2 (C2) in the adjacent Lapita midden area appears to represent a rapid build up with little significant change in ceramic styles (Spriggs and Bedford 2013). The natural top soil (Layer 1; C1) overlying this midden build up had sparse Lapita age materials brought up from Layer 2 (C2) below (Petchey et al 2014). This material appears to have been largely *in-situ* at the interface between Layer 1 and Layer 2 and comprising similar assemblages to those below (Spriggs and Bedford 2013). However, the *in-situ* ceramics at the interface and within Layer 1 (C1) appear to show the most significant changes in vessel form compared to the Layer 2 (C2) assemblage as dentate stamped and incised pottery declined and notched rim sherds increased (Spriggs and Bedford 2013). Recent articulated historic farm animal skeletons were superimposed within the natural topsoil (Layer 1; C1).

All the evidence points to the early Lapita cemetery phase having been a permanent continuous settlement occupied for a few generations. The burials were not associated with a single event but with a succession of complex and varied mortuary events judging by the pottery scatters and reburial of skeletons and skeletal elements once decomposition had occurred (Bedford et al 2010; Valentin et al 2010). Isotopic evidence (Bentley et al 2007) and limited cases of intercutting or disturbance by later burials also supports the short time period of use by a few generations (Bedford et al 2010).

### *3.3.2 Post-cemetery period (Late Lapita period to ca. 2500 BP)*

The significance of the cemetery (or its memory) was lost and a thick post-cemetery midden Layer 2 (B2-B1) rapidly built up covering the entire cemetery and B2 may overlap temporally with the adjacent Lapita midden (C3-C1) area. It ranged from 50 to120cm in thickness with increasing depth down the slope of the upraised reef (from south to north) and represented a substantial post-cemetery cultural deposition. Based

on midden composition, and ceramic style and form, this Layer 2 midden was divided into two distinct spatio-temporal assemblages B2 and B1.

Unit B2 comprised the basal 10-40cm of Layer 2 and was similar and may have overlapped temporally with the adjacent Lapita midden area (C3-C1). The midden content of B2 was dense and associated with concentrated giant tortoise and shellfish remains and Lapita and Arapus vessel forms (Bedford et al 2010). A thin anthropogenic brown subsoil layer could sometimes be seen at the interface between Layer 3 and Layer 2. This could represent either a brief transition in cultural activity, a gap in settlement following the end of funerary practices at the site or a post-deposition sedimentary development between the contact points of Layers 2 and 3. Due to its ephemeral nature it was not considered as a separate temporal unit from other basal Layer 2 (B2) deposits.

Later Erueti period settlement (Layer 2; B1) overlying Lapita periods (D, B2) eventually covered the cemetery area and a much wider area to the north indicating that the site expanded over time, possibly in response to both a prograding shoreline and/or increasing settlement population. Lapita and Arapus ceramic styles were largely restricted to B2 and D below. However, small numbers of Lapita sherds were found in B1 which is considered here a result of excavation methods near the contact point with Lapita and also minor upwards movement of items post-deposition. In the upper part of Layer 2 (B1) there appears to have been a drastic reduction of vessel form and decorative technique over time coinciding with an increase in globular out curving rim and flat wide lipped pots associated with Early Erueti ceramics (c. 2800-2500 BP). The latter ceramic sequences having been established elsewhere on Efate (Bedford et al 2006).

By the end of the sequence the Teouma settlement was abandoned or possibly moved some distance closer to the rapidly prograding shoreline and a thick weathered tephra-rich alluvial topsoil (A), like that covering the Lapita midden (C1), developed over the last few thousand years.

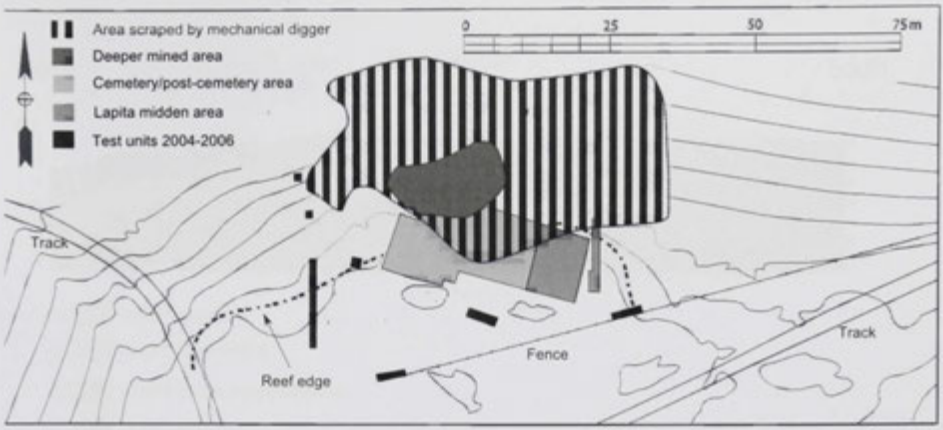


**Figure 3-3: Teouma site map with cemetery/post-cemetery and Lapita midden areas.**

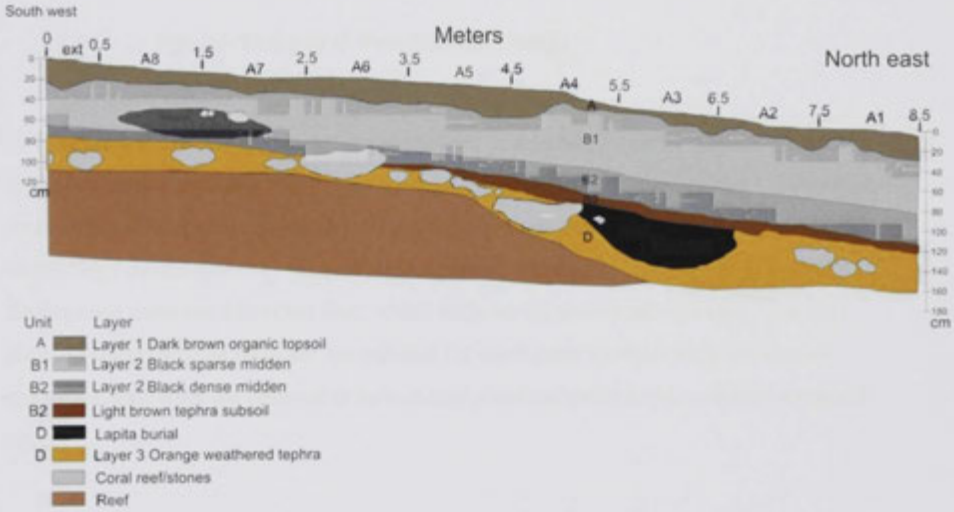


**Figure 3-4: Lapita cemetery (Unit D) and post-cemetery Lapita midden (Unit B2) and Post-Lapita midden (Units B1, A) 2004 trench 3a stratigraphy northeast to southwest axis.**

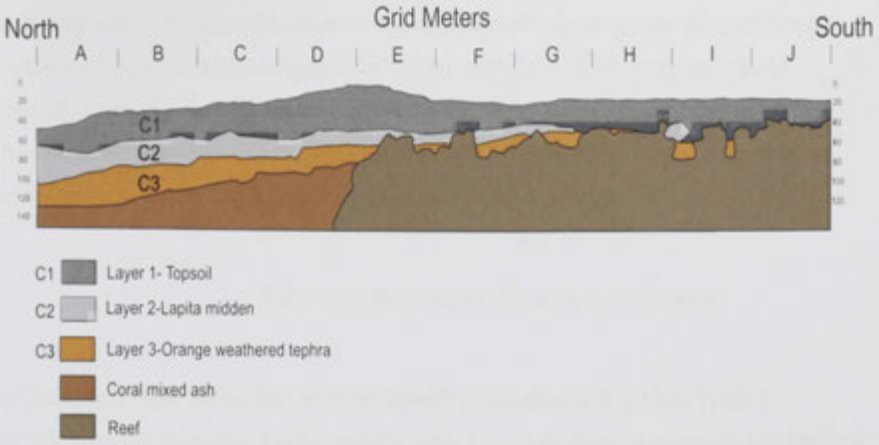


**Figure 3-5: Lapita midden stratigraphy (Units C3-C1), Area 2ext eastern baulk**

## 3.4 Spatio-Temporal Provenance Units

In Chapter 1 it was stated that temporal changes in subsistence patterns were a central aim of this thesis and this requires analysing vertebrate assemblages within a diachronic framework. The appropriate analytical aggregated units (based upon the archaeological chronology outlined above) for analysing temporal trends are explicitly described here. Provenance units are described first, which includes all associated contexts. However, because some of these units are not suitable for diachronic analysis these are further organized into what are referred to here as analytical temporal units or simply temporal units.

Applications of Optimal Foraging Models to zooarchaeological data typically concern cumulated time averaged deposits and aggregations of vertebrate assemblages within distinctive spatio-temporal units, which comprise only unequal portions of a time continuum (Lyman 2003). However, this aggregation has the potential to influence changes in taxonomic relative abundance. The effects of aggregation can also arbitrarily reduce measures of variability that do not translate ecological real time (for which optimal foraging models were designed for) into archaeological time (Grayson and Delpech 1998). Lyman (2003) expresses concern for bias through spatio-temporal aggregation when sampling size issues relating to the number of unique spatio-temporal assemblages, or NASM (number of assemblages) as he refers to it, are used in analysis.

He further describes, within each NASM, NCTXspace (number of unique spatial contexts) and NCTXtime (Number of unique temporal contexts), that form different portions of a spatial temporal sequence. These spatial-temporal aggregations are typically compromised by the cumulative nature of the archaeological record which is the sum of an unknown number of foraging events from uncertain time periods by an unknown number of participants (Grayson and Delpech 1998).

### *3.4.1 Spatio-temporal provenance units*

At Teouma at least seven NASM were identified, listed as unit A-G in Table 3.1. NCTXspace = 3 including Lapita midden (Unit C), cemetery/post-cemetery undisturbed area (Units A, B, D), and the Area 7c to the south (Unit M). NCTXtime = 2 which includes the Lapita cemetery (Unit D) and Lapita midden (Unit C), and the post-cemetery Lapita and Erueti midden (Unit B, A). Units A, B, and D encompass a much larger excavation area than C (Table 3.1) and the disparity in excavation volume is therefore likely to have some influence on relative sample sizes of each unit. Primarily due to disturbances to part of the site and uncertainty around some contexts, Units E and F were excluded as analytic units for diachronic study. Unit G (Area 7c) was not disturbed but was considered to be too complicated for temporal analysis due to the increased spatial aggregation this would have brought and the uncertain temporal relationship to Units A-D when weighing up the likely return in information it may have provided.

**Table 3-1: Teouma provenance units (NASM=7)**

| Unit | Layer | Provenance | Ceramics | Area m² |
|---|---|---|---|---|
| A | 1 | post-cemetery | Early-Erueti | 353 |
| B | 2 | post-cemetery | Early-Erueti/Lapita | 353 |
| D | 3 | cemetery | Lapita | 353 |
| C | 1 to 3 | Lapita midden | Lapita | 120 |
| E | 1 to 3 | earthwork mounds | Early-Erueti/Lapita | 0 |
| F | 2 to 3 | digger disturbed | Early-Erueti/Lapita | 0 |
| G | 1 and 3 | Area 7c | Early-Erueti/Lapita | 5 |

### *3.4.2 Analytic spatio-temporal units*

After selecting appropriate undisturbed provenance units, focus was concentrated on developing a fine grained analytic temporal resolution in two distinct spatial contexts (NCTXspace =2) reflecting the spatial variation in cemetery and adjacent settlement deposits (Figure 3.5). These include the Lapita midden area (Units C1, C2, C3, NASM=3) and undisturbed cemetery/post-cemetery area (Units A, B1, B2, D, NASM=4) which comprise a combined NASM of 7 (Table 3-2).

Spits, while recorded within these spatio-temporal units, were not considered for diachronic analysis because the layers appear to provide adequate temporal resolution with respect to cultural materials and avoids the difficulty in aggregating by depth, which varied with slope.

Despite the problems with translating ecological time into archaeological time outlined above, this section outlines how the analytical temporal units, associated with accumulated spatio-temporal provenance units at Teouma, were aggregated. Humans can deposit materials at various rates which are not likely to remain constant as many variables such as population size and duration of time spent at the site could vary. Another problem is the potential for temporal changes in the degree of animal bone fragmentation which could have a serious effect on NISP (Number of Identified Specimen Present) as a means of quantification. Other studies have suggested that NISP, MNE (Minimum Number of Elements) and MNI (Minimum Number of Individuals) are strongly correlated indicating that with large samples quantification methods do not affect relative rank abundances (see Grayson 1984). The validity of the data with respect to changes in fragmentation rates and effects on NISP will be tested in Chapter 8 by exploring NISP: MNE ratios by temporal unit for certain taxa.

**Table 3-2: Teouma Analytic Temporal Units (NASM=7)**

| Unit | Layer | Provenance | Ceramics | Area m2 | Recovery procedure |
|---|---|---|---|---|---|
| A | 1 | post-cemetery | Erueti | 353 | Hand excavation |
| B1 | 2 | post-cemetery | Erueti | 353 | Dry sieve 5mm |
| B2 | 2 | post-cemetery | Lapita | 353 | Dry sieve 5mm |
| D | 3 | Lapita cemetery | Lapita | 353 | Wet sieve 1-2mm |
| C1 | 1 | Lapita midden | Lapita | 120 | Judgemental dry sieve 5mm |
| C2 | 2 | Lapita midden | Lapita | 120 | Wet sieve 1-2mm |
| C3 | 3 | Lapita midden | Lapita | 120 | Wet sieve 1-2mm |

## 3.5 Recovery procedures

In Chapter 2 it was discussed how recovery techniques are of the utmost importance in recovering significant and representative faunal samples. In this section the recovery procedures practiced by analytic temporal unit at Teouma are discussed. Ideally recovery methods should be practiced in a consistent manner across all temporal units when studying diachronic subsistence changes. But they also have to be balanced between the efficacy of their contribution and time constraints. With this in mind a disparate number of recovery methods were employed to achieve a range of project objectives.

A graded judgemental recovery sampling strategy was employed which resulted in differential recovery methods between the cemetery (D) and Lapita midden (C3-C1) compared to those used with the post-cemetery period cultural deposits (B2-B1). Cultural remains were most abundant in the cemetery period Lapita temporal units and these contexts were considered of the highest priority. Therefore materials from these spatio-temporal contexts were recovered using the finest grained recovery methods which involved wet sieving of all sediments through 1-2mm mesh. Cultural remains, while abundant in the very early post-cemetery Lapita Layer 2 midden deposits (B2), tended to dramatically decline with decreased depth/age of deposit (B1, A). Dry sieving through larger 5mm sieves was employed for most of these temporal units with the exception of four 1x1m$^2$ squares, chosen at regular intervals along a north/south transect, where material was wet sieved through 1-2mm screens. The Layer 1 topsoil for both the Lapita midden and post-cemetery areas had the sparsest cultural deposits. This was tested by judgemental sampling where sieving was conducted so long as an abundance of cultural items were being recovered. Sieving of this layer was generally abandoned only when cultural remains became sparse, and once this happened material recovered was done so by hand during excavation.

Differential recovery methods between the cemetery/Lapita midden units (fine grained recovery) and the post-cemetery midden deposits (coarse grain) could potentially influence patterns of relative abundance and sample size over time. Tests on the differential recovery methods of Pacific fish fauna have determined that smaller sieve

screen sizes can increase taxonomic diversity with a greater number of smaller fish species represented (Densmore 2009; Gordon 1993; Nagaoka 1994, 2005a). Large sieve sizes tend to favour greater proportions of larger sized taxa. Also larger skeletal elements tend to be recovered in greater abundance relative to smaller elements within specific taxa (Nagaoka 2005a). These patterns are not a general rule as there are exceptions that reflect preservation conditions and the presence of smaller diagnostic specimen (Vale and Gargett 2002). Wet sieving through small mesh sizes has also been reported to significantly increase recovery of greater bone samples, and greater proportions of small taxa than those recovered from dry sieving as a result of the sediment being washed through the sieve improving visibility of faunal remains (Casteel 1976; James 1997).

Such tests have yet to determine the differential effects of screen size and wet sieving versus dry sieving on the recovery of different sized Pacific non fish taxa but experiments on fauna elsewhere have indicated that there is a bias towards recovery of increased proportions of very small mammal remains recovered using smaller size sieves (e.g. Shaffer and Sanchez 1994). Vale and Gargett (2002) argue that differential screen size affects the relative abundance of certain taxa such as mammal more than fish because mammals have a greater number of diagnostic skeletal elements per individual. Studies on the differential recovery methods of bird and reptile remains are even rarer (e.g. Clason and Prummel 1977).

Based on these studies and the differential recovery methods employed at Teouma, it could be expected that a greater representation of smaller taxa relative to larger taxa could be present in the Lapita cemetery phase of settlement compared to the post-cemetery overlying midden deposits. This would not be an ideal scenario considering the results of any diachronic change could potentially be the result of recovery methods rather than a real trend in prehistoric subsistence behaviour. To control for this differential recovery it was decided in the field to wet screen post-cemetery deposits from Layer 2 from four 1m² units in Area 3a (squares 4.2, 4.4, 4.6, 4.8) using the 1-2mm mesh as used for recovery within the early cemetery and Lapita midden deposits.

Statistical analysis was used to test the validity of differential recovery techniques of bird, mammal, and reptile bones at Teouma. Comparisons between the proportions of large and small taxa (by NISP) from the dry sieved 5mm samples versus the wet sieved

1-2mm samples in these post-cemetery control samples were tested (see Tables 3-3, 3-4, 3-5, 3-6 for raw data used). This required a few basic steps. First, total numbers of large mammal and reptile identified and unidentified bones and bone fragments (ΣLarge specimen NISP), and small mammal, bird and reptile identified and unidentified NISP (ΣSmall taxa NISP) were calculated for both the wet sieved (1-2mm) and dry sieved (5mm) samples for each analytic post-cemetery temporal unit (B1-B2). Next the ratio of both small and large taxa (for these two samples by temporal unit) were converted into an index, i.e. small B2/B1 taxa index (ΣSmall specimen NISP B2/ ΣSmall specimen NISP B1) and the large B2/B1 taxa index (ΣLarge specimen NISP B2/ΣLarge specimen NISP B1). The large and small taxa B2/B1 indexes for both the wet sieved and dry sieved samples by temporal unit were then statistically tested for any significant difference using a chi-square test.

The results from this analysis (Table 3-7) indicate that there was no significant difference in the proportions of large and small taxa between the wet screened 1-2mm samples compared to the 5mm dry sieved samples ($X^2 = 0.36$, $P=0.6$) indicating that differential recovery methods did not have a statistically significant effect on the size of taxa being recovered and should therefore have no effect on relative abundance when comparing the cemetery period faunal data with the post cemetery faunal data. It is most likely that these differential recovery procedures did result in much lower sample sizes for the post-cemetery temporal units. But these data would suggest that 5mm dry sieving is an adequate sampling strategy for the recovery of Vanuatu terrestrial fauna, the smallest of which are rats, fruit bats and small birds which are well represented in both cemetery and post-cemetery assemblages regardless of recovery method. Therefore all subsequent diachronic analysis of post-cemetery temporal assemblages is conducted using the combined dry sieved and wet sieved samples from units B2-B1.

**Table 3-3: Post-cemetery temporal units, 5mm dry sieved sample, small taxa by NISP.**

| Small Taxa | B1 | B2 |
|---|---|---|
| Accipiter fasciatus | 0 | 14 |
| Anas superciliosa | 0 | 11 |
| Bird | 99 | 499 |
| cf Aplonis | 0 | 3 |
| cf Chalcophaps indica | 1 | 3 |
| cf Columba vitiensis | 1 | 5 |
| cf Ducula goliath | 1 | 3 |
| cf Ducula pacifica | 9 | 35 |
| cf Gallicolumba stairii | 1 | 1 |
| cf Gallirallus philippensis | 0 | 6 |
| cf Gallus | 1 | 19 |
| cf Megapodius | 0 | 5 |
| cf Passerine | 0 | 2 |
| cf Porphyrio melanotus | 0 | 7 |
| cf Pseudobulweria rostrata | 0 | 1 |
| cf Pteropodidae | 175 | 1030 |
| cf Ptilinopus | 0 | 1 |
| cf Ptilinopus greyii | 4 | 1 |
| cf Rattus | 1 | 0 |
| Chalcophaps indica | 3 | 7 |
| Columba vitiensis | 5 | 13 |
| Columbid | 0 | 2 |
| Columbid small | 0 | 11 |
| Didunculus nsp | 0 | 3 |
| Ducula pacifica | 10 | 28 |
| Egretta alba | 0 | 1 |
| Gallicolumba sp. | 0 | 2 |
| Galliform indet | 0 | 2 |
| Gallirallus philippensis | 10 | 7 |
| Gallus | 12 | 66 |
| Lizard | 0 | 1 |
| Megapodius | 3 | 24 |
| Passerine | 9 | 27 |
| Porphyrio melanotus | 20 | 78 |
| Porzana tabuensis | 1 | 2 |
| Pteropodidae | 580 | 4636 |
| Ptilinopus | 0 | 1 |
| Ptilinopus greyii | 0 | 1 |
| Rattus exulans | 182 | 187 |
| Rattus praetor | 16 | 42 |
| Rattus sp. | 97 | 134 |
| Sula leucogaster | 1 | 5 |
| Todiramphus chloris | 0 | 2 |
| Tyto alba | 0 | 3 |
| Total | 1242 | 6931 |

**Table 3-4: Post-cemetery temporal units, 5mm dry sieved sample, large taxa by NISP.**

| Large Taxa | B1 | B2 |
|---|---|---|
| ?M. Damelipi | 16 | 818 |
| ?Mekosuchus | 1 | 0 |
| cf Sea turtle | 0 | 20 |
| cf Pig | 0 | 19 |
| cf tortoise | 6 | 325 |
| Sus scrofa. | 227 | 1818 |
| Reptile | 10 | 909 |
| Sea turtle | 1 | 24 |
| Turtle | 2 | 160 |
| Medium mammal | 162 | 1983 |
| Total | 425 | 6076 |

**Table 3-5: Post-cemetery temporal units, 1-2mm wet sieved sample, small taxa by NISP**

| Small taxa | B1 | B2 |
|---|---|---|
| cf Chalcophaps indica | 0 | 1 |
| cf Ducula pacifica | 0 | 1 |
| cf Pteropodidae | 15 | 19 |
| Columba vitiensis | 0 | 1 |
| Columbid small | 0 | 2 |
| Ducula pacifica | 0 | 6 |
| Gallirallus philippensis | 1 | 0 |
| Gallus | 1 | 0 |
| Bird | 9 | 29 |
| Megapodius | 0 | 1 |
| Passerine | 3 | 1 |
| Porphyrio melanotus | 1 | 5 |
| Porzana tabuensis | 1 | 0 |
| Pteropodidae | 45 | 144 |
| Rattus exulans | 9 | 13 |
| Rattus praetor | 1 | 1 |
| Rattus sp. | 12 | 4 |
| Total | 98 | 228 |

**Table 3-6: Post-cemetery temporal units, 1-2mm wet sieved, large taxa by NISP**

| Large taxa | B1 | B2 |
|---|---|---|
| ?M. Damelipi | 1 | 54 |
| cf M. Damelipi | 1 | 1 |
| Medium mammal | 25 | 45 |
| Reptile | 0 | 28 |
| Cheloniidae | 0 | 1 |
| Sus scrofa | 14 | 32 |
| Total | 41 | 161 |

**Table 3-7: Dry sieved 5mm and wet sieved 1-2mm sieving strategy by post-cemetery temporal units B1 and B2 ($X^2$ =0.36, P=0.6).**

| | Sieve strategy B2/B1 | |
|---|---|---|
| Taxa | Dry 5mm | Wet 1-2mm |
| Small | 5.58 | 2.33 |
| Large | 14.3 | 3.93 |

## 3.6 Vertebrate assemblage

Central to zooarchaeology studies are methods of anatomical and taxonomic classification. This requires the accurate sorting into bird, fish, shellfish, mammal, and reptile classes and then identification of faunal specimen to the most specific taxonomic and anatomical classification possible (for an outline of how this is applied to Pacific fauna see Leach 1986). Inaccurate identifications can greatly affect true patterns of prey selection so careful consideration was made to identify specific taxa only when absolutely confident. Identifications of archaeological vertebrate specimens were made based on morphological comparison with modern, paleontological and archaeological reference specimens held at museums and universities in conjunction with morphometric analysis in the case of some taxa. Skeletal elements were identified in a consistent manner by side; portion, segment diagnostic zones and fraction summation in a coding system adapted from North American bison kill site studies (Todd 1987; n.d.) to the Teouma vertebrate assemblages. As is often the case with fragmented archaeological faunal assemblages, in many cases vertebrate specimen could only be identified into broad classes of fish, bird, mammal and reptile based on microstructure and minimal morphological features. A specimen that came close to meeting identification criteria was given a cf prefix.

The preservation conditions at Teouma were excellent and the bones appear to be mostly unaffected by degeneration, due to weathering or chemical diagenetic processes. The midden by its nature is a much more actively churned deposit during the time of deposition than what the cemetery unit D would have been. This could have led to more heavy breakage in the midden. The combined spatio-temporal vertebrate mammal, reptile and bird assemblages at Teouma even without including fish remains is the largest faunal assemblage from any Lapita site in the Pacific with 49212 non-fish vertebrate specimens, and at least 57 distinct taxa identified. The most ubiquitous

vertebrate remains are those of fruit bat (*Pteropodidae*) pig (*Sus scrofa*) (note identification to species is based on preliminary DNA and geomorphometric analysis conducted by others), rat (*Rattus sp*) and tortoise (*?Meiolania damelipi*) (Figure 3-6). Figures 3-7 and 3-8 show the vertebrate data organized into specific categories by temporal unit based on three broad subsistence strategies practised at Teouma. They include hunting large game reptiles (tortoise, crocodile, sea turtle), hunting of small game birds and fruit bats probably in close proximity to the site, and the management or predation of commensal taxa (pig, chicken, rat). The sample sizes vary by provenance unit due to disparities in excavation size, recovery methods and temporal trends in prehistoric resource acquisition between these different units. Most of the vertebrate remains were concentrated in the post-cemetery Lapita midden (Unit B2), with significant vertebrate samples also from the cemetery Unit D and Lapita midden Unit C (Figure 3-7). Clearly small taxa dominate all assemblages except Unit A which was mostly un-sieved but commensal taxa are well represented and appear to increase in proportion over time, while small proportions of large game fluctuate (Figure 3-8).

In this section I report on the Teouma mammal, bird, and reptile vertebrate remains and discuss the relative contexts of each taxa or group of taxa necessary to interpret the data in the core chapters to follow, including regional context, current status, ecological habitats, and in some cases capture methods. I then discuss identification issues for the taxa and how this affected taxonomic classifications.

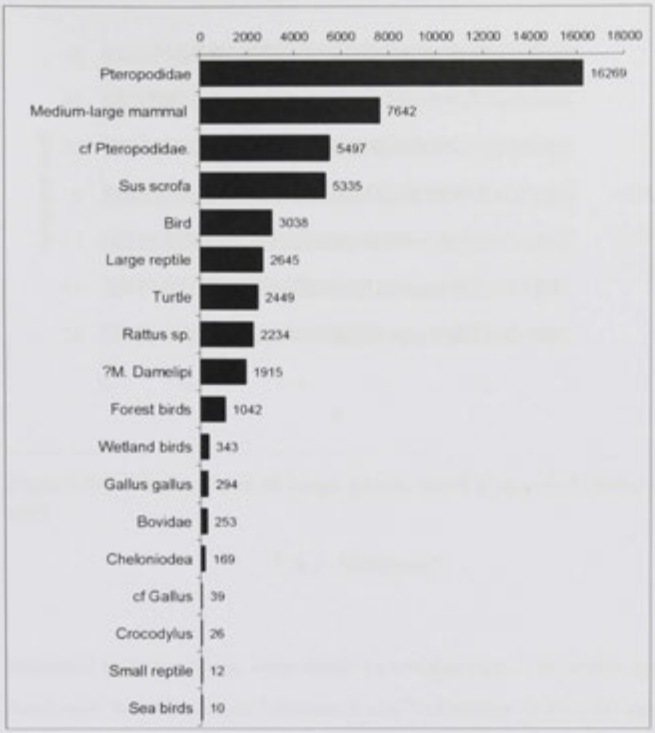


**Figure 3-6: Total NISP (NISP=49,212) all provenance units combined**


**Figure 3-7: NISP, large game reptiles (tortoise, sea turtle, crocodile), small game (bird, fruit bat) and commensal animals (pig, chicken, rat) from the domestic patch by temporal unit (see Table 6-1 for raw data).**

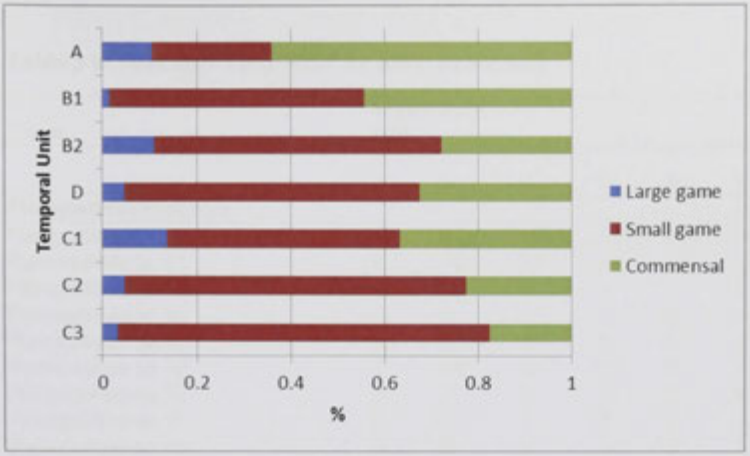


**Figure 3-8: Proportions of large game, small game and commensals by temporal unit**

### *3.6.1 Mammals*

Mammal identifications were made by comparison to reference specimen held at the Auckland War Memorial Museum Land Vertebrate Collection and the Australian National University Archaeology and Natural History Osteology Reference Collection. In total, 37,229 mammal specimens representing at least eighteen species were recovered from all provenance units at Teouma and are listed in Table 3-8. These include at least thirteen unidentified fruit bat species (*Pteropodidae*), and Lapita introduced invasive mammals including pig (*Sus scrofa*) and two species of rat (*Rattus exulans, Rattus praetor*). The cattle and sheep/goat remains (see Figure 3-6 and Table 3-8) were clearly recent depositions still in articulation on the surface and in the top soil of Layer 1 in Unit C and so these are excluded from further discussion.

**Table 3-8: Mammal Taxa NISP by provenance unit**

| Taxon | Provenance Unit | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | G | Grand Total |
| **Pteropodidae** Fruit bats | | | | | | | | |
| Pteropodidae | 17 | 6155 | 6018 | 2292 | 472 | 343 | 20 | 15317 |
| Pteropodidae sp.1? | 2 | 109 | 47 | 18 | 10 | 5 | 1 | 192 |
| Pteropodidae sp.1a | 0 | 17 | 1 | 1 | 1 | 5 | 0 | 25 |
| Pteropodidae sp.1b | 0 | 2 | 1 | 1 | 0 | 1 | 0 | 5 |
| Pteropodidae sp.1c | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 2 |
| Pteropodidae sp.1d | 0 | 24 | 34 | 25 | 8 | 0 | 0 | 91 |
| Pteropodidae sp.1e | 0 | 2 | 3 | 0 | 2 | 0 | 0 | 7 |
| Pteropodidae sp.1f | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| Pteropodidae sp.1g | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 2 |
| Pteropodidae sp.1h | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| Pteropodidae sp.1i | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| Pteropodidae sp.1j | 0 | 2 | 3 | 0 | 1 | 0 | 0 | 6 |
| Pteropodidae sp.1k | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| Pteropodidae sp.1m | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| Pteropodidae sp.2 | 1 | 238 | 234 | 87 | 25 | 17 | 0 | 602 |
| Pteropodidae sp.3 | 0 | 11 | 3 | 0 | 1 | 0 | 0 | 15 |
| cf Pteropodidae | 5 | 1550 | 2893 | 804 | 139 | 41 | 65 | 5497 |
| **Muridae** Rats | | | | | | | | |
| *Rattus exulans* Pacific rat | 7 | 412 | 189 | 193 | 18 | 5 | 15 | 839 |
| *Rattus praetor* New Guinea Spiny rat | 1 | 69 | 61 | 77 | 5 | 6 | 5 | 224 |
| *Rattus sp.* | 5 | 273 | 465 | 314 | 11 | 9 | 94 | 1171 |
| cf Muridae | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 2 |
| **Artiodactyla** Ungulates | | | | | | | | |
| *Sus scrofa* domestic pig | 36 | 2653 | 1195 | 635 | 509 | 267 | 40 | 5335 |
| *cf Sus scrofa* | 0 | 19 | 1 | 6 | 1 | 0 | 0 | 27 |
| *Bos taurus* Cattle | 0 | 0 | 20 | 0 | 0 | 0 | 0 | 20 |
| *Ovis aries* sheep | 0 | 0 | 231 | 0 | 0 | 0 | 0 | 231 |
| Bovidae cattle/sheep/goat | 0 | 0 | 2 | 0 | 0 | 1 | 0 | 3 |
| **Identified mammal** | 74 | 11539 | 11408 | 4453 | 1204 | 700 | 240 | 29618 |
| **Unidentified mammal** | 54 | 2671 | 2134 | 1888 | 295 | 223 | 346 | 7611 |
| Total | 128 | 14210 | 13542 | 6341 | 1499 | 923 | 586 | 37229 |

### 3.6.1.1 Fruit bat (*Pteropodidae*)

In Vanuatu today there are fourteen extant native species of bat (Prié 2011), including four mega-bat fruit bat species from the *Pteropodidae* family (two of which are endemic) from two sub families, *Pteropodinae* and *Macroglossinae*. These include members of the *Pteropodinae* sub family (the Pacific flying fox *Pteropus tonganus geddiei*, the endemic Banks flying fox *Pteropus fundalus* and the endemic Vanuatu flying fox *Pteropus anetianus*) and from the *Macroglossinae* sub family the much smaller Fijian blossom fruit bat *Notopteris macdonaldi* (Flannery 1995b). There are also

ten very small Microchiroptera (micro-bat) bat species, including two recently discovered species (*Nyctophilus sp.*, *Chaerephon jobensis*) (Prié 2011). Vanuatu bats mostly originate from ISEA and Papua New Guinea but also share species in common with New Caledonia and Fiji (Flannery 1995b; Medway and Marshall 1975; Prié 2011).

Most of the bat species are very small cave dwelling species including the ten Microchiroptera which weigh anywhere between 5 to 20 grams (see Flannery 1995b for description of eight). *Chaerephon bregullae*, the largest of these small bats at 20 grams, has been reportedly hunted in caves by villagers on Vanua Levu in Fiji (Flannery 1995b:403). *Miniopterus australis* was the most common and numerous cave dwelling Microchiroptera bat encountered during the Santo 2006 expedition with up to 50,000 recorded in a single cave colony (Prié 2011: 320). It is therefore possible to mass capture large numbers of these small bats in caves quite easily using fire, sticks, nets and stones as reported by Flannery in the afore mentioned Fijian example.

Of the Vanuatu fruit bats, only the Fijian blossom fruit bat roosts and breeds in large caves and is the smallest weighing 71-60.8 gm. They forage in montane forest environments (Flannery 1995b: 219; Prié 2011) making them less susceptible to agriculturally induced environmental change in the lowlands. The other three extant fruit bat species all tend to congregate in arboreal colonies of various sizes. Of these species, the Pacific Flying Fox is the largest with an average weight of 570 grams (males) and 473 (females) grams. They can weigh upwards of 1000 grams (Flannery 1995b: 294-296) and are also one of the most widespread fruit bats in the Pacific. On Santo the Pacific flying fox has been recorded from sea level to 1000m in a variety of habitats including lowland, intermediate and highland forest, mangroves, and agricultural cultivated land (Prié 2011: 318), making it one of the most adaptable bats that is resistant to environmental change. They breed in large loud colonies in large trees along the shoreline between September to January and by June females leave to form female only camps far inland to give birth in late August to early September, while males disperse and both groups become difficult to find (Mickleburgh et al 1992). They are a popular food item in Vanuatu where hunting of the Pacific Flying Fox with guns, stones, and trapping in baited flat bottomed baskets fixed in trees is often employed (MacGillivray 1860). The other two endemic fruit bats, the Vanuatu Flying Fox (353 grams males, 340 grams females) and the smaller Banks Flying Fox (224 grams males, 187.3 grams females) both extant in Vanuatu today, are much smaller and yet they often

have been recorded roosting in sympatric large noisy Pacific Flying Fox roosts on Efate (Flannery 1995b). The Vanuatu Flying Fox also tends to roost in small quiet colonies (Chambers and Esrom 1989).

*Pteropodidae* was clearly the most ubiquitous taxa in all the Teouma provenance assemblages by NISP, indicating that fruit bats were naturally abundant within the terrestrial environment near Teouma at the time the site was occupied. Bat skeletal material was identified against modern fruit bat specimen held at the ANU Archaeology and Natural History reference collection with the aid of illustrations (Giannini et al 2006). The majority of the fruit bat bones were cranial and post cranial bones and these were simply identified to *Pteropodidae*. In addition, at least thirteen (as yet unidentified) fruit bat species based on distinctive mandible morphology (Figure 3-9) were identified as type specimens within the mega-bat *Pteropodidae* family level in a similar approach applied to Pleistocene fruit bats in Near Oceania (White et al 1991; Marshall and Allen 1991). This number may expand to sixteen but some incomplete mandible portions means that there is some potential overlap for three of the type specimens. Type specimen characterizations were based on mandible size and morphology (Type 1a-n Large, Type 2 medium, Type 3 small) for now, although there may also be some potential for assigning crania and some long bones to species. This approach of using size and morphology is likely to be valid as there not many juvenile bat bones represented in the assemblage (see Chapter 7). Fourteen of the type specimens represent large species, one medium, and one small. All appear larger than micro-bat species present in Vanuatu today.

It is now apparent that at least nine species of fruit bat, present in small numbers in the early deposits, disappeared from the later post-cemetery provenance units. The most frequent bat mandible type specimen are 2, 1d and 1a, which continue throughout the Teouma sequence. More detailed taxonomic identifications and novel bat descriptions will be later conducted by bat zoology specialists.

MacDonald (2002) summarizes prehistoric fruit bat exploitation in the Pacific since the Pleistocene with notable studies in Near Oceania of sporadic occupations in cave sites at Balof (White et al 1991), Panakiwuk (Marshall and Allen 1991) and at Buka in the Solomon Islands (Wickler 2001). Lapita period fruit bat studies, however, are limited and characterized by small quantities of bones, usually identified to Order, or by size

when identified to genus or species. Recent studies of Vanuatu faunal material from the immediately Post-Lapita period have started to change this view indicating that fruit bats were more significant to Lapita diet than previously thought (Bedford 2006a; MacDonald 2002).


**Figure 3-9: Teouma fruit bat type specimen mandibles (with exception of specimen 1o, 1p, 1q from Vao, northern Vanuatu) characterized by size and morphology.**

### 3.6.1.2 Pig (*Sus scrofa*)

Pigs were noted in Vanuatu in 1606 A.D. by Quiros' companions (Kelly 1966), and Kelly (1966) also linked these pigs to *Sus papuensis* in the belief that they were introduced from Papua New Guinea at some point in prehistory. Since then it has become accepted based on MtDNA and patchy archaeological evidence that Pacific domesticated pigs *Sus scrofa* were first introduced to Vanuatu via Southeast Asia and ISEA by Lapita colonists (Dobney et al 2008). Today pigs play a crucial role in Vanuatu socio-political spheres through regulated feasts to grade chiefly power through demonstrations of wealth. Feral pigs are also hunted for meat (McIntyre 1997; Weightman 1989).

The Teouma pig remains were identified in great abundance throughout the sequence and it is the largest assemblage and most significant evidence of Lapita pig management since its introduction into the Asia-Pacific. The pig remains could only be identified to genus Sus sp, based on skeletal morphology, compared against a range of modern Asia-Pacific *Sus scrofa* reference specimens of various ages. An early attempt was made by Judith Robbins of the University of Auckland to extract MtDNA in an effort to identify a more specific lineage but the DNA in the specimens was too degraded. Recent ancient DNA and geomorphometric analysis, however, has now confirmed that Teouma pigs are *Sus scrofa* from the Pacific clade as expected (Keith Dobney, Anna Linderholm, Allowen Evin pers com 2014).

#### 3.6.1.3 Rat (*Rattus)*

It is generally accepted that a number of rat species were deliberately distributed widely throughout the Pacific by colonizing populations (Matisoo-Smith 2007). Rats present in Vanuatu today include the Pacific rat *Rattus exulans* and recently introduced European species Black rat *Rattus rattus* and Brown rat *Rattus norvegicus*. Two rat species, however, appear to have been introduced quite early during the colonization of Vanuatu. The Pacific rat was introduced with Lapita people into Vanuatu (Bedford 2006a: 227) and the New Guinea Spiny rat *Rattus praetor* has been identified in association with mostly immediately Post-Lapita deposits dating around 2700 BP on north west Malekula and western Efate (Bedford 2006a; White et al 2000). In Fiji it has been found in association with Lapita deposits (White et al 2000). The New Guinea Spiny rat appears to have disappeared from the fossil record rather recently and is no longer found in the Remote Oceania region (White et al 2000).

Rat species are found in a variety of habitats. These include disturbed habitats in close proximity to human settlements, forest and grassland environments (Flannery 1995b). The large New Guinea Spiny rat is common in disturbed habitats (Flannery 1995a), is sympatric with the Pacific rat and other species but appears less competitive in relation to other species. The Pacific rat in particular remains extant and widespread in the Pacific region today despite the historic introductions of European rat species.

Rats have the potential to reach dense biomasses, in some cases even greater than large herbivorous mammals (Madsen et al 2006). During initial colonization when the food supply would have been more plentiful, rat populations may have exploded. Rats have been considered important food items in other parts of the Pacific, such as in New Zealand where ethnographic accounts have recorded large numbers of rats caught in pits in a single night, but they were also often caught in snares set along rat trails in the forest (Best 1979: 242-253). Ethnographic accounts of rats exploited for food in Vanuatu are limited to Tanna Island in southern Vanuatu (Speiser 1996).

Rat taxa in this thesis are later included in the domestic patch despite their potential as commensal animals that were dying naturally within midden deposits. It is very difficult to distinguish between natural and consumed rat deposits in the archaeological record (Colman 1998). Rat gnawing marks were quite common on many of the animal bones (from all temporal units) in the midden deposits and on human skeletal remains buried in the cemetery. This indicates that rats naturally lived in close proximity to prehistoric human settlement at Teouma. In a few cases whole rat skeletons were found buried in holes indicating rats were tunnelling and dying naturally in the deposits. Only 0.8% of the rat remains (18 bones) showed signs of obvious burning, one of which was partially burnt, indicating flesh was still on the bone while it was being burnt. Another bone had cut marks on it. It is therefore likely that the rat remains at Teouma are made up of a combination of natural mortality and consumption and no attempt is made in this thesis to discern the difference and the rat bone assemblage is treated as a whole.

Approximate identifications to species are inferred based on morphological differences in maxilla as well as morphometric measurements (see Driesch, A, von den 1976). This analysis could characterize in many cases rat bones as either the Pacific rat or New Guinea Spiny rat in comparison with published measurements of both species from Vanuatu prehistoric deposits (White et al 2000). Using this comparative data, a clear distinction was made between these two species, which is unlikely to reflect sexual dimorphism. Bones that had no measurement or morphological data were simply identified to genus *Rattus sp.* At Teouma the two different sized rat species (Figure 3-10) are demonstrated consistently by two groups of measurements. These are consistent with White el al (2000) data for the smaller Pacific rat (Table 3-9), and the larger New Guinea Spiny rat (Table 3-10), which is nearly twice as large, from all temporal units. The maxillary tooth morphology from these two different sized groups is also consistent

with comparison to reference material and relative descriptions by White et al (2000) where the New Guinea Spiny rat has more rounded and less complex cusps than the Pacific rat (Figure 3-11). This has also been confirmed by geomorphometric analysis (Keith Dobney pers. com 2014) and confirms that both Pacific rats and New Guinea Spiny rats arrived in Vanuatu simultaneously with the first Lapita settlement of the region.

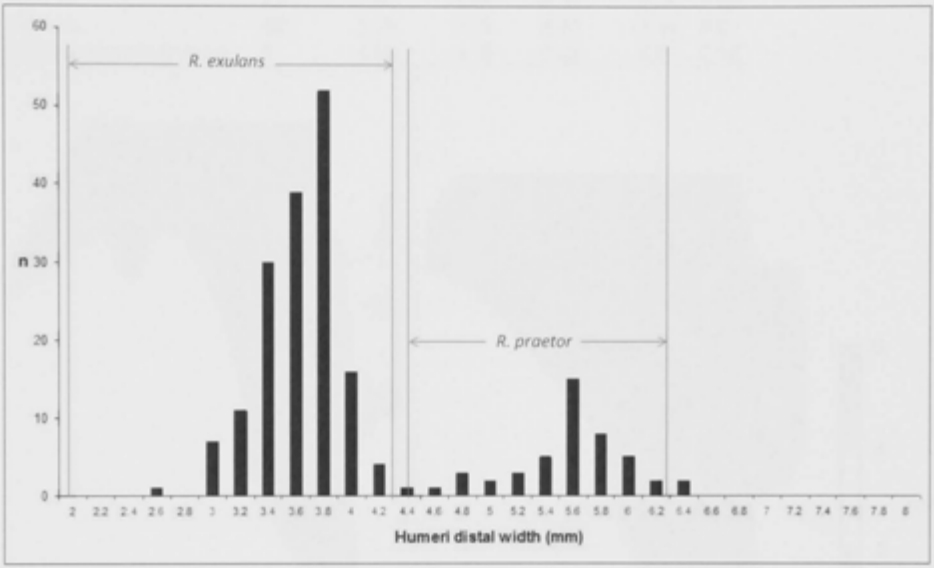


**Figure 3-10: Teouma Rat distal humeri width by NISP. *R. exulans* Pacific rat (left) and *R. praetor* the New Guinea Spiny rat (right) within the ranges (Blue lines) established by White et al (2000) for Vanuatu specimen from both species.**

**Table 3-9: Teouma *R. exulans* mandibular and post cranial long bone dimensions (mm). Measurements follow White et al 2000 and von den Driesch 1976.**

| Element/portion | N | Mean | Median | S.D. | Min | Max |
|---|---|---|---|---|---|---|
| Humerus pr | 47 | 3.39 | 3.37 | 0.159 | 3.16 | 3.92 |
| Humerus ds | 162 | 3.73 | 3.77 | 0.28 | 2.67 | 4.31 |
| Femur pr | 296 | 4.41 | 4.47 | 0.39 | 3.04 | 5.29 |
| Femur ds | 91 | 4.06 | 4.09 | 0.2 | 3.46 | 4.76 |
| Mandible m1-m3 | 77 | 5.47 | 5.43 | 0.30 | 4.68 | 6.18 |
| Tibia pr | 173 | 3.69 | 3.6 | 0.43 | 2.16 | 4.93 |
| Tibia ds | 133 | 2.57 | 2.58 | 0.15 | 2.07 | 2.9 |
| Scapula glenoid max bd | 5 | 2.86 | 2.79 | 0.18 | 2.76 | 3.18 |

**Table 3-10: Teouma *R. praetor* mandibular and post cranial long bone dimensions (mm). Measurements follow White et al 2000 and von den Driesch 1976.**

| Element/portion | Number | Mean | Median | S.D. | Min | Max |
|---|---|---|---|---|---|---|
| Humerus pr | 6 | 4.93 | 4.9 | 0.16 | 4.71 | 5.16 |
| Humerus ds | 47 | 5.67 | 5.71 | 0.43 | 4.55 | 6.54 |
| Femur pr | 69 | 7.31 | 7.4 | 0.68 | 5.65 | 8.73 |
| Femur ds | 5 | 6.65 | 6.82 | 0.32 | 6.15 | 6.91 |
| Mandible m1-m3 | 37 | 7.24 | 7.22 | 0.59 | 6.22 | 9.01 |
| Tibia pr | 23 | 5.6 | 5.51 | 0.35 | 5.02 | 6.68 |
| Tibia ds | 42 | 3.79 | 3.72 | 0.41 | 3.24 | 5.5 |
| Scapula glenoid max bd | 4 | 4.83 | 4.79 | 0.22 | 4.6 | 5.12 |

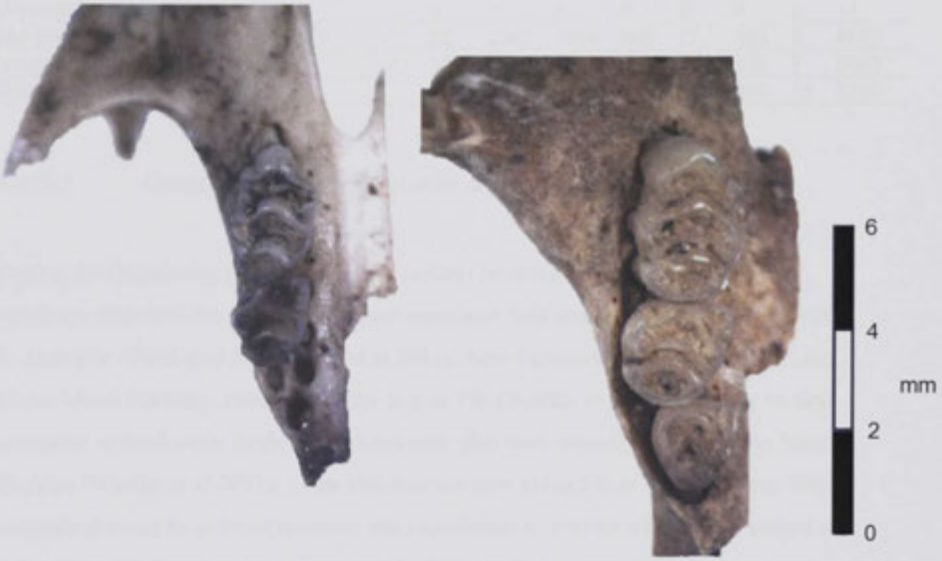


**Figure 3-11: Right upper rat maxilla from Teouma (Ventral view), *Rattus exulans* (left), *Rattus praetor* (right).**

### *3.6.2 Reptiles*

The reptile faunal assemblage numbered 7,216 vertebrate specimens representing at least five taxa, including two species and three Orders (Table 3-11). In addition a few small lizard (Squamate; skinks and geckos) bones were identified but could not be identified to a lower taxonomic level. These are most likely a later natural deposition and not likely to have been part of the prehistoric diet.

**Table 3-11: Reptile Taxa NISP by provenance unit**

| Taxa | A | B | C | D | E | F | G | Total |
|---|---|---|---|---|---|---|---|---|
| **Testudine**Turtles | | | | | | | | |
| *?Meiolania Damelipi* Giant Vanuatu Tortoise | 9 | 1296 | 292 | 161 | 47 | 105 | 5 | 1915 |
| *cf ?M. Damelipi* | 9 | 498 | 260 | 132 | 20 | 35 | 0 | 954 |
| *Cheloniidae* Marine turtle | 0 | 33 | 115 | 18 | 1 | 2 | 0 | 169 |
| *cf Cheloniidae* | 0 | 22 | 305 | 1 | 0 | 1 | 0 | 329 |
| Unidentified turtle | 4 | 188 | 702 | 240 | 9 | 20 | 3 | 1166 |
| **Crocodylidae** Crocodile | | | | | | | | |
| Crocodylidae Unidentified crocodile | 0 | 0 | 16 | 10 | 0 | 0 | 0 | 26 |
| cf Crocodyloidea | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 2 |
| **Squamata** Lizards and Snakes | | | | | | | | |
| Unidentified Lizard Gecko/skink | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| Unidentified Snake | 0 | 3 | 8 | 0 | 0 | 0 | 0 | 11 |
| Identified Reptile | 22 | 2042 | 1699 | 562 | 77 | 163 | 8 | 4573 |
| Unidentified Reptile | 14 | 1268 | 1041 | 172 | 36 | 105 | 7 | 2643 |
| Total Reptile | 36 | 3310 | 2740 | 734 | 113 | 268 | 15 | 7216 |

### 3.6.2.1 Giant Tortoise (*?Meiolania damelipi*)

During the Quaternary period, giant land turtles (from now on referred to as giant tortoises) inhabited the Asia-Pacific from mainland Asia and ISEA (Corlett et al 2010) to Australia (Field et al 2008; Price et al 2011), New Caledonia (Gaffney 1984), Lord Howe Island (Gaffney 1996) and as far east as Fiji (Worthy et al 1999). Large bodied terrestrial or freshwater turtle fossils have now also been recently discovered in New Zealand (Worthy et al 2011). Giant tortoises are now extinct from these regions. This evidence derives from fossil deposits and association or overlap with human arrival was not established due to the extremely patchy fossil record. Extant giant tortoise species still exist in the Galapagos Islands in central eastern Pacific and Aldabra atoll in the Seychelles Islands, of the Indian Ocean, as well as in the neotropics. Islands in the Indian Ocean and the Galapagos Islands were settled rather late by Europeans and historic accounts of giant tortoise hunting and anthropogenic environmental impacts and their recent extinctions and depletions caused by Europeans are particularly well documented on Madagascar, the Mascarenes, the Seychelles and the Galapagos Islands (Bourn et al 1999; Cheke and Hume 2008; Iverson 1982; Pedrono 2008; Van Denburgh 1914).

Tortoises are reptiles and reptiles do not stop growing throughout the course of their long life spans (Jackson Jr et al 1976). Giant tortoises have been recorded in incredibly

dense biomasses (35000 kg per km²) on the Aldabra Atoll in the tropical Indian Ocean (Coe et al 1979; Gerlach et al 2013), due to high adult survivorship in the absence of predators. Such longevity can also fluctuate due to changes in ecological conditions, climatic cycles and carrying capacity limitations (Bourne et al 1999; Gerlach et al 2013). Tortoises, however, are especially vulnerable to human predation due to delayed sexual maturity, which can be approximately 20 years (Swingland and Coe 1979) for giant Aldabra tortoises, and high juvenile mortality (Iverson 1982). Because many tortoise species require a high adult survivorship to offset high egg and juvenile mortality this is a problem when the largest adult specimens (females) are the first to be targeted by humans.

Giant tortoises for the most part are broad-diet herbivores, frugivores and omnivores with highly adaptive digestive systems (Bonin et al 2006; McMaster and Downs 2008), which allow them to occupy a range of vegetation habitats ranging from coastal shrub, central highlands, dry deserts, and rainforests (Hansen et al 2008; Pedrono 2008). As such they are capable of adapting to virtually any environment including rather marginal island environments. Tortoises are considered keystone species in many ecosystems because they are important seed dispersers (Hansen et al 2008; Jerozolimski et al 2009). They are also important in creating and maintaining habitat heterogeneity by trampling or digging burrows (Means 2006). As giant tortoises have coevolved with vegetation over time shaping tortoise-plant interactions, tortoise extinctions on islands have resulted in severely degraded island environments (Griffiths et al 2010; Hansen et al 2008).

The recent identification of *?Meiolania damelipi*, a new extinct species of giant tortoise, at Teouma (White et al 2010) is the first demonstration of prehistoric human impact on giant tortoise populations in the Asia-Pacific, and has drastically changed what we know about Vanuatu paleoecology and Lapita subsistence adaptation to terrestrial island ecologies in the region. *?Meiolania damelipi* is the most abundant reptile species in the Teouma vertebrate assemblage, concentrated in the earliest provenance units in the cemetery/Lapita midden as well as the post-cemetery Lapita midden (see Chapter 6). Very small quantities of tortoise bones are found in the upper Erueti deposits at Teouma but these we attribute to slight disturbances and minor overlapping excavation and recovery at the interface between Lapita and Erueti horizons. It appears that giant tortoises quickly disappeared from the archaeological record after only 100-200 years as

Lapita culture transitioned to Post-Lapita traditions. Four more sites in Vanuatu, on Vao and Uripiv islets off Malekula, Port Olry on Santo and Arapus on Efate have also yielded tortoise bones in association with Lapita (or immediately Post-Lapita in the case of Arapus) deposits with only small quantities found in later Lapita contexts. Now a similar extinct giant tortoise species has been discovered from two Fijian Lapita sites, Yanuca and Naigani, which as yet are unreported and un-described (Hawkins unpublished data). It is now clear that the pre-Lapita distribution of giant tortoises in Remote Oceania and associated Lapita tortoise hunting appears to have been much more extensive than previously thought.

Identification of tortoise was first confirmed in 2008, with the assistance of Brian Gill the curator of the Auckland War Memorial Museum land vertebrate reference collection. This was achieved through comparison of archaeological turtle humeri with a single fossil *Meiolanidae platyceps* humerus reference type specimen, #LH1559, recovered from calcareous beach sand deposits at Hunter Bay Lord Howe Island and held in the Museum collections. These distinctive reptilian skeletal elements had to be carefully identified by comparison initially with marine turtle reference collections to distinguish between the two orders followed by more detailed comparisons with the help of Trevor Worthy at the Australian Museum in Sydney. A large number of turtle shell (carapace and plastron bone) fragments were also present in the archaeological deposits and these were characterized either as cf *?M. damelipi* or cf sea turtle (Cheloniidae) based on microstructure and surface morphology. *?M damelipi* bones appear quite distinctive having a porous fibrous surface morphology in comparison to the smoother sea turtle bone surface. But in many cases this was indeterminate and where this occurred, specimens were identified as turtle (Testudine) only.

The zoological description of the Vanuatu giant tortoise can be found in White et al (2010), but since this description, cranial and mandibular elements have been discovered (see Figure 3-12). Compared to *Meiolania platyceps* clear differences for *?Meiolania damelipi* were noted including more gracile long bones with less expanded ends. Similarities in premaxilla and mandible ridges were noted during comparisons with an Australian Museum *Meiolania Platyceps* specimen AM F:16860 and MM F:13825 (see Gaffney 1983 figures 30 and 32), although the Vanuatu tortoise maxillary and mandibular ridges appear jagged in comparison to the flat ridges of *Meiolania Platyceps*. The Vanuatu tortoise, while clearly a novel species remains of uncertain

lineage, which is why its genus attribution has a question mark. This uncertainty of origin may be resolved in future by comparison to a greater range of type specimens from various taxonomic associations and origins. Ancient DNA analysis could also help to resolve this issue.


**Figure 3-12: Vanuatu Giant Tortoise *?Meiolania damelipi*. (Left) cranial left premaxilla ventral view. (Right) Mandible dorsal view.**

### 3.6.2.2 Sea Turtle (Cheloniidae)

Sea turtle remains are commonly found in great abundance within archaeological deposits in the Pacific during initial colonization phases. These decline drastically in later periods (Allen 2007) indicating changes in predation strategies either in response to rapid resource depression as a result of human predation, or changes in cultural practices. Unlike terrestrial taxa, sea turtles can re-colonize island regions, but their numbers had declined dramatically in the last few decades due to customary harvesting in Vanuatu (Hickey and Johannes 2002; Petro et al 2007). Recent conservation measures have recently been introduced and adopted at the village level with marked success as evidenced by a revival in recorded numbers (Hickey and Johannes 2002). Four sea turtle species have been recorded visiting Vanuatu shores and waters today. Loggerhead *Caretta caretta* and leatherback *Dermochelys coriacea* are less common in Vanuatu but the Green turtle *Chelonia mydas*, and the Hawksbill *Eretmochelys*

*imbricata* are still common (Ineich 2011:190). The Green turtle is the most common sea turtle in Vanuatu. It is herbivorous, feeding on sea grass and seaweed implying active migration from feeding to reproduction areas (beaches) and can concentrate in rookery egg laying sites (Ineich 2011). It is a relatively large species and highly prized by some island communities in the Asia-Pacific for its meat (Bliege-Bird and Bird 1997). Hawksbill is the second most common sea turtle in Vanuatu waters but its reproduction in Vanuatu has never been confirmed (Ineich 2011: 191). The Hawksbill is highly valued for its shell, which can be made into a variety of decorative or functional items, but the meat is not considered very edible (Frazier 2005). Leatherback turtles nest along the coast of Malekula in small numbers (Petro et al 2007), but otherwise are found in deep waters (Ineich 2011).

At prehistoric sites, in Vanuatu and the Pacific, sea turtle remains are usually not identified to species nor are details of skeletal elements usually provided. Only sea turtle post cranial elements were identified at Teouma. Leatherback turtles, the only extant member of the *Dermochelyidae* family, have distinctive long bones (Wyneken and Witherington 2001) and these were eliminated from the list of potential sea turtle species present in the Teouma vertebrate assemblage. The other six extant global sea turtle species from the *Cheloniidae* family, however, can only be identified from scutes, which don't survive in the archaeological record, and cranial and mandibular skeletal elements (Wyneken and Witherington 2001), which were not present at Teouma. Sea turtle identifications, therefore, were kept to the *Cheloniidae* family level. I have previously identified sea turtles to species from cranial and mandibular fragments at other Lapita sites in Vanuatu, including Hawksbill from the Vao Lapita site and Hawksbill and Green turtle from the Uripiv Lapita site (Hawkins unpublished data).

#### 3.6.2.3 Crocodile (Crocodyloidea)

Two crocodile species have been recorded in Vanuatu. An extinct species of terrestrial crocodile *Mekosuchus kalpokasi* has been identified from a mandible recovered from the immediately Post-Lapita Arapus site on the west coast of Efate (Mead et al 2002). Today the Indo-Pacific estuarine salt water crocodile *Crocodylus porosus* still has a remnant population on Vanua Lava in the Banks Islands, Northern Vanuatu, particularly in the Silver River. This population has declined steadily over time due to cyclones and

hunting (Chambers and Esrom 1993) and is now facing imminent extirpation from Vanuatu (Ineich 2011).

Only small amounts of crocodile remains were identified (Figure 3-13) and only from the very initial Teouma temporal contexts in the cemetery and adjacent Lapita midden. These were only identified to super family level *Crocodyloidea* due to the lack of reference material and the difficulty in distinguishing salt water crocodile from terrestrial dwarf crocodile (*Mekosuchine*) skeletal morphology. Comparison of Teouma crocodile teeth with reference collections at the Auckland Museum did, however, present a close match for salt water crocodile based on size and morphology.


**Figure 3-13: Teouma crocodile skeletal elements. Top left: scutes, bottom left: saltwater crocodile sized teeth, left to right: Right humerus, left humerus, left femur (rat gnawed), caudal vertebrae.**

### *3.6.3 Birds*

In total 4,767 bird bones were identified, 1,727 to taxon. Thirty-four distinctive taxa (including thirteen new records), three quarters of which are now extinct, were identified by palaeofauna specialist Dr. Trevor Worthy of Flinders University. The full identifications and descriptions of new previously unidentified extinct species are reported in Worthy et al (accepted) but the preliminary identifications are outlined here in Table 3-12. The bird assemblage includes members of one family, three distinctive genera and twenty-seven species (six of which are tentative, Table 3-12) with

taxonomic identifications and nomenclature following Clements (2012). Twenty of these taxa (including eighteen species, one family, and one genus) are still found in Vanuatu today. Ten taxa (including nine species and one genera) are now extinct or extirpated from modern Vanuatu. These include three new endemic species never before recorded in the Pacific: a giant Megapode, Lini's megapode *Mwalau walterlinii*, an undescribed large pigeon *Columbidae large nsp 1* and a large rail yet to be described *Rallidae nsp*, as well as the extinct Tongan Tooth-billed pigeon *Didunculus placopedetes* from Tonga.

Seven specific and conspecific taxa not recorded in modern Vanuatu but known in other parts of the Pacific region, include the Himalayan Cuckoo *Cuculus saturatus*, Goliath Imperial Pigeon *Ducula cf goliath*, Sacred Kingfisher *Todiramphus cf sanctus*, ?Coenocorypha (sandpiper) a wader shorebird, Blyth's Hornbill *Rhyticeros cf plicatus* from Papua New Guinea and Melanesia, Tongan ground dove *Gallicolumba cf G. stairii* from Polynesia and the Australian White Ibis *Threskiornis cf molucca* (an intertidal flats and fresh/saltwater wetlands bird). Finally, a large pigeon identified to the Genus *?Caloenas* could be a new species endemic to Vanuatu although it could also be the now extinct *C. canacorum* found in sub fossil deposits in New Caledonia (Balouet and Olson 1989) and Tonga or *C. nicobarica* the only living member of this genus and distributed from ISEA to the Solomon Islands (Steadman 2006a).

In Vanuatu this diverse avifauna has adapted to specific niches within a range of terrestrial lowland and montane rain forests, open woodlands, disturbed agricultural habitats, wetland and lake environments, and coastal environments (e.g. Barre et al 2011; Brugella 1992; Diamond and Marshall 1977a; 1977b; Marshall and Medway 1975). As such the Vanuatu avifauna offers the potential to investigate subsistence behaviour in a more detailed analysis of specific terrestrial patch exploitation. The origin of the Vanuatu avifauna is mostly Papuan (Diamond and Marshall 1976; Medway and Marshall 1975). In Vanuatu today 130 (Barre et al 2011; Bregulla 1992; Doughty et al 1999; Marshall and Medway 1975) bird species have been recorded in the Vanuatu archipelago, including 50 sea bird species (27 oceanic, 23 coastal) (many of which are seasonal migrants or rare non breeding vagrants), 20 freshwater aquatic birds from various wetlands, lakes, rivers, and swamps, and 59 forest birds (21 open forest habitat, 38 lowland and montane forest).

Forest birds make up the majority of bird taxa exploited at Teouma with nineteen taxa from a range of forest and open forest habitats including the extinct species Lini's megapode *Mwalau walterlinii* and two pigeons Tongan Tooth-billed pigeon *Didunculus placopedetes* and *Columbidae large nsp 1*, and a potential new extinct species of pigeon of the Genus *Caloenas*. Extant forest bird taxa present, including tentative identifications, are the Vanuatu Scrub-fowl *Megapodius layardi*, Starling-forest bird *?Aplonis*, Palm lorikeet *?Charmosyna palmarum*, Mackinlay's Cuckoo-dove *Macropygia mackinlayi*, Red-bellied fruit dove *Ptilinopus greyii*, Emerald dove *Chalcophaps indica*, Metallic pigeon *Columba vitiensis*, Pacific Imperial pigeon *Ducula pacifica*, Imperial pigeon *Ducula goliath*, Himalayan Cuckoo *Cuculus saturates*, Tongan Ground-dove *Gallicolumba cf stairii*, Sacred King-fisher *Todiramphus sanctus*, and the Lapita introduced chicken *Gallus gallus*. All inhabit tropical rain forest to various altitudes.

Open habitat/forest edge birds include the Australian Barn-owl *Tyto delicatula* and the Brown Goshawk *Accipiter fasciatus*, the latter since extirpated from Efate Island (Steadman 2006a). Some birds were once forest species but have adjusted well to habitat change from deforestation and thrive in more open or forest edge environments such as the Australian Barn-owl, Buff banded rail, and the white collared kingfisher (Brie 2011). Interestingly the only extant endemic bird species present in the Teouma assemblage is the Vanuatu Scrub-fowl, but this has recently been found in archaeological deposits at Tikopia (Steadman et al 1990, Steadman 2006a Table 5-10:150) and Nuembo lomlom (Steadman 2006a) while Mackinlay's Cockoo-dove is also endemic to Vanuatu and Reef Santa Cruz Islands which are geographically associated with Northern Vanuatu. The Goliath Imperial Pigeon was considered endemic to New Caledonia (Doughty et al 1999: 114) and has never before been recorded in Vanuatu. Native species on the IUCN red list are the Vanuatu Scrub-fowl, Bakers Imperial pigeon, and Palm Lorikeet. The Pacific Imperial pigeon are also much less numerous today (Barre et al 2011).

There are nine aquatic bird taxa from a variety of freshwater swamp, lake and river habitats present in the Teouma assemblage. These include a new undescribed extinct large rail species *Rhallid nsp*. Extant native species include Spotless crake *Porzana tabuensis*, Purple swamphen *Porphyrio melanotus*, Great egret *Ardea alba*, Buff-banded rail *Hypotaenidia philippensis*, Pacific Black duck *Anas superciliosa*, Australian White

Ibis *Threskiornis cf molucca* and the Collared king-fisher *Todiramphus cf chloris*. Today some aquatic bird species are close to being endangered, including the spotless crake and some petrel colonies. The Pacific Black duck are also much less numerous then they once were, attributed by Brugella (1992) to over hunting and habitat disturbance from cumulative human settlement encroachment (Barre et al 2011) while the Australian White Ibis is no longer seen in Vanuatu (Brugella 1992; Doughty et al 1999).

The five sea bird taxa present in the assemblage are found along Vanuatu coasts or in Vanuatu waters today. Many of the oceanic birds can also be found along coastal environments and so are included within the coastal patch. Some are oceanic seasonal migrants including the Wedge-tailed Shearwater *?Puffinus pacificus*, Tahiti Petrel *?Pseudobulweria rostrata*, and an unidentified small *Procellariid sp.* Resident sea birds including the Brown Booby *Sula leucogaster* and Sandpiper s cf *Coenocorypha* have breeding populations in Vanuatu today (Brugella 1992).

**Table 3-12: Avifauna taxa NISP per provenance unit.**

| Taxon | A | B | C | D | E | F | G | Total |
|---|---|---|---|---|---|---|---|---|
| **Accipitridae** Kites, Hawks, Harriers | | | | | | | | |
| *Accipiter fasciatus* Brown Goshawk | 0 | 15 | 1 | 3 | 1 | 1 | 0 | 21 |
| *Accipiter cf fasciatus* | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| **Anatidae** Ducks, geese, swans | | | | | | | | |
| *Anas superciliosa* Pacific Black Duck | 0 | 11 | 0 | 1 | 2 | 0 | 0 | 14 |
| *cf Anas superciliosa* | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 2 |
| **Rallidae** Rails | | | | | | | | |
| *Porphyrio melanotus* Purple Swamphen | 2 | 141 | 27 | 10 | 37 | 1 | 6 | 224 |
| cf Porphyrio melanotus | 0 | 12 | 7 | 1 | 1 | 0 | 0 | 21 |
| *Hypotaenidia philippensis* Buff-banded Rail | 0 | 39 | 13 | 3 | 5 | 2 | 0 | 62 |
| *Porzana tabuensis* Spotless Crake | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 5 |
| *lge rail undescribed sp.* | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| Rallid | 0 | 2 | 2 | 2 | 1 | 0 | 0 | 7 |
| **Columbidae** Pigeons and Doves | | | | | | | | |
| *Ducula pacifica* Pacific Imperial Pigeon | 0 | 76 | 32 | 13 | 6 | 2 | 1 | 130 |
| cf Ducula pacifica | 0 | 66 | 62 | 16 | 4 | 6 | 9 | 163 |
| *Ducula cf goliath* Goliath Imperial Pigeon | 0 | 4 | 27 | 5 | 0 | 1 | 0 | 37 |
| Ducula sp. | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| cf Ducula sp. | 0 | 1 | 0 | 2 | 0 | 0 | 0 | 3 |
| *Columba vitiensis* Metallic Pigeon | 0 | 23 | 10 | 9 | 0 | 0 | 1 | 43 |
| cf Columba vitiensis | 0 | 9 | 13 | 2 | 0 | 1 | 1 | 26 |
| *Didunculus placopedetes* Tongan tooth-billed pigeon | 0 | 3 | 37 | 1 | 0 | 1 | 0 | 42 |
| cf Didunculus placopedetes | 0 | 0 | 8 | 1 | 0 | 0 | 0 | 9 |
| *Chalcophaps indica* Common Emerald Dove | 0 | 13 | 21 | 4 | 0 | 0 | 0 | 38 |
| cf Chalcophaps indica | 0 | 6 | 7 | 1 | 0 | 0 | 0 | 14 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Columbidae Large Pigeon sp 1* | 0 | 0 | 21 | 1 | 0 | 0 | 0 | 22 |
| *Ptilinopus cf greyii* Red-bellied Fruit Dove | 0 | 14 | 1 | 1 | 0 | 0 | 1 | 17 |
| *Macropygia cf mackinlayi* ?Mackinlay's Cuckoo-Dove | 0 | 3 | 9 | 0 | 0 | 0 | 0 | 12 |
| *Caloenas sp.* Pigeon | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 2 |
| *Gallicolumba cf stairii* Tongan Ground Dove | 0 | 2 | 5 | 0 | 0 | 0 | 0 | 7 |
| Columbidae Pigeon | 0 | 24 | 56 | 16 | 0 | 0 | 0 | 96 |
| **Cuculidae** Cuckoos | | | | | | | | |
| *Cuculus optatus* Oriental Cuckoo | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 |
| **Scolopacidae** Sandpipers | | | | | | | | |
| cf *Coenocorypha* Sandpiper | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| **Psittaculidae** Parrot | | | | | | | | |
| cf *Charmosyna palmarum* Palm Lorikeet | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 3 |
| Unidentified Psittaciforme Small Parrot | 0 | 0 | 2 | 1 | 0 | 0 | 0 | 3 |
| **Procellariidae** Petrels, shearwaters, prions | | | | | | | | |
| cf *Pseudobulweria rostrata* Tahiti Petrel | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| cf *Puffinus pacificus* Wedge-tailed Shearwater | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| *Puffinus cf Bailloni* Abudon's Shearwater | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| **Threskiornithidae** Wading Birds | | | | | | | | |
| Threskiornis cf molucca Australian White Ibis | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| **Bucerotidae** Hornbills | | | | | | | | |
| *Rhyticeros cf plicatus* Blyth's Hornbill | 0 | 0 | 5 | 1 | 0 | 0 | 0 | 6 |
| **Sulidae** Gannets and Boobies | | | | | | | | |
| *Sula leucogaster* Brown Booby | 0 | 6 | 1 | 0 | 0 | 0 | 0 | 7 |
| **Sturnidae** Starlings | | | | | | | | |
| cf Aplonis sp | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 3 |
| **Halcyonidae** Tree Kingfishers | | | | | | | | |
| *Todiramphus cf chloris* Collared Kingfisher | 0 | 2 | 0 | 3 | 0 | 0 | 1 | 6 |
| **Ardeidae** Herons | | | | | | | | |
| *Ardea alba* Great Egret | 0 | 1 | 0 | 0 | 2 | 0 | 0 | 3 |
| **Strigidae** Barn-owls | | | | | | | | |
| *Tyto delicatula* Australian Barn-owl | 0 | 3 | 7 | 4 | 0 | 0 | 0 | 14 |
| **Passeriformes** Song Bird | | | | | | | | |
| Unidentified Passerine | 0 | 43 | 33 | 15 | 0 | 0 | 3 | 94 |
| **Galliformes** Game birds | | | | | | | | |
| *Gallus gallus* Red Jungle-fowl | 6 | 94 | 66 | 82 | 25 | 10 | 11 | 294 |
| cf *Gallus gallus* | 0 | 21 | 4 | 12 | 1 | 1 | 0 | 39 |
| *Mwalau walterlinii* Lini's megapode | 0 | 0 | 46 | 0 | 0 | 0 | 0 | 46 |
| *Megapodius layardi* | 0 | 45 | 99 | 13 | 6 | 1 | 0 | 164 |
| cf Megapodius layardi | 0 | 6 | 2 | 1 | 1 | 0 | 0 | 10 |
| Megapodius / Gallus | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| Unidentified Galliform | 0 | 2 | 3 | 2 | 0 | 0 | 0 | 7 |
| Identified Bird | 8 | 697 | 635 | 231 | 93 | 27 | 36 | 1727 |
| Unidentified Bird | 4 | 815 | 1620 | 396 | 63 | 28 | 114 | 3040 |
| Total Bird NISP | 12 | 1512 | 2255 | 632 | 156 | 56 | 150 | 4767 |

# 4 Evolutionary Ecology, Optimal Foraging Model Predictions and Alternative Perspectives of Faunal Utilization

## 4.1 Introduction

In Chapter 2, limitations of zooarchaeological data and analytical perspectives were identified as factors contributing to only a very general understanding of the process of Lapita subsistence change. This chapter goes into detail outlining the research design for modelling subsistence change during the Lapita/Post-Lapita transition at Teouma, Efate Island, Vanuatu. It attempts to overcome these limitations and thus provide a much more detailed account of Lapita ecological interactions, the impact this had on Efate Island ecology and how this may have affected subsequent subsistence strategies at Teouma.

Evolutionary ecology was selected as the theoretical framework for this thesis for two main reasons; Firstly, because it is deductive it offers the ability to develop a research design focused on generating predictions for varied human behaviour aimed at increasing reproductive fitness (Smith and Winterhalder 1992). These predictions can then be tested using multiple zooarchaeological datasets with a range of specific methods (i.e. Broughton et al 2011). It therefore affords a very concise and well organized research design focused on clear and achievable outcomes to demonstrate optimal versus non optimal behaviour. Secondly, because of the potential of such studies to delineate fine resolution of subsistence change, it is considered here appropriate for the abundant vertebrate samples associated with well-defined spatio-temporal contexts at Teouma. Framed within socio-ecological contexts during the Lapita – Post-Lapita transition this study builds on past historical ecology studies (outlined in Chapter 2) to document Lapita-ecological interactions in a way that is more theoretically robust and methodologically rigorous. Further, well established ceramic sequences at Teouma and other sites on Efate Island that demonstrate rapid change allow the rare application of Optimal Foraging Models (OFM) to be applied to very short phases of a prehistoric sequence.

This research design explains in detail the evolutionary ecology theoretical framework using OFM and costly signalling theory to generate predictions of how humans interacted with the ecology during the transition from Lapita to Post-Lapita periods, as well as the analytical procedures used to test these predictions. OFM used in this study,

include Diet Breadth Model, Prey Choice Model, Patch Choice Model, Central Place Foraging Model and Marginal Value Theorem (MVT) which predict what prey and resource patches humans exploit over time. Costly signalling provides an alternative socio-cultural theoretical perspective to human evolutionary behaviour to improve reproductive fitness. These studies typically are carried out on prehistoric foraging cultures but this study is a first as it adapts these models to the Neolithic mixed economy of the Lapita culture outlined in Chapter 2.

## 4.2 Human Behavioural Ecology

### *4.2.1 Theory overview and critical summary*

Evolutionary ecology otherwise referred to as human behavioural ecology (HBE) in anthropological applications is a materialist theory based on the simple overriding premise that human behaviour as it adapts to ecological systems can be linked in some way to natural selection (Broughton and O'Connell 1999; Smith and Winterhalder 1992). It follows that organisms behave in ways within their ecological context that maximize survival and reproductive fitness by maximizing energy returns while foraging for subsistence. Much of this materialist approach was driven by the need to move away from qualitative casual statements of environmental possibility with regards to subsistence change, as part of the new archaeology of the 1970s, and there began a move more towards explicit studies that quantify subsistence change. This charge was led by evolutionary ecology which was at the time being used in the biological fields to explain variation in animal feeding behaviour (MacArthur and Pianka 1966). Applying this evolutionary principle to more complex organisms like humans to explain how they made foraging decisions was the next logical step. Many reviews in the literature reveal significant discord amongst scholars due to inherent problems with the theory and its applicability to archaeology (see Broughton and O'Connell 1999; Krebs 1978; Lupo 2007; Shennan 2002; Smith 1983; Smith and Winterhalder 1992; Stephens and Krebs 1986; Winterhalder 1981; Winterhalder and Smith 1981, 1992, 2000) and so it will be reiterated here in only the briefest of detail.

The, as yet scientifically undemonstrated, link between human behaviour and genetics has led to questions of the validity of HBE as a theory and has raised serious implications that suggest human behaviour cannot be controlled if it is predetermined by genes which could be used in justifying social injustices (Shennan 2002). Despite this, many researchers now accept that human behaviour evolves by means of a combination of genetics and cultural transmission through social learning (Broughton and O'Connell 1999; Dunnell 1980; Shennan 2002; Smith and Winterhalder 1992). Shennan (2002) argues that this 'phenotypic gambit' allows humans the phenotypic flexibility to adapt behaviour under selection and to avoid confusion we should see it as a series of average maximizing behaviours by groups of people over time and not any particular behaviour by any particular individual. This form of evolution has cultural selection acting on behaviour indirectly through genes even in cases where behaviour is learned and so in the strictest of senses is not Darwinian evolution. Others choose to ignore evolution and refer to a kind of economic rationalization (Smith and Winterhalder 1992).

Many take issue with the materialist nature of HBE. People interacting with the environment to make optimal subsistence decisions to maximize reproductive fitness should not be considered a general law as there are many ethnographic and historical cases of non-optimal subsistence behaviour. It is a theory by which predictions can be made about what optimal subsistence behaviour should look like in the archaeological record. But most importantly (unlike satisficer subsistence) optimal subsistence behaviour can be quantified explicitly in the archaeological record (Smith and Winterhalder 1992). As Bettinger (1991: 105) puts it "the real test is whether observed behaviour conforms to expectations arising from the models". Bettinger (1991: 106) further argues that OFM allows the measurement of rational economic behaviour as a yardstick to be tested to distinguish rational and irrational behaviour.

Others, most notably from another evolutionary theoretical faction based on strict Darwinian selectionist theory led by Dunnell (1980, 1992), ask the question how can a theory be scientific if we lack the methods to directly observe behaviour in the archaeological record and, therefore, how can we make scientific laws which can predict human behaviour? This is a criticism that can be laid at any archaeological theory. Dunnell argued that we should not attempt to use evolutionary theory to link human behaviour with ecological variables because there is too much uncertainty from

the data. His solution was to look at evolution from a different perspective by focusing on a bottom-up inductive approach where specific observations from archaeological data should shape the generalized theory. In this way he suggests it is possible to avoid seeing things in the data that aren't there by making models using unscientific laws. To this end he argued that changes in functional aspects of artefacts which form part of the human phenotype, and are therefore subject to the same evolutionary aspects as biology, can be linked to the most optimal outcome, increasing fitness (Dunnell 1980). Broughton and O'Connell (1999) argue that it is not possible to avoid making laws about human behaviour when applying theory to the archaeological record and question whether it is possible to design a comprehensive research methodology without some clearly defined deductive framework from which to work from.

Yet despite understandable selectionist and anti-materialist objections, HBE has become the most popular paradigm with which to explain subsistence change using archaeofaunal data with an explosion of research over the last 30 years especially on prehistoric foraging cultures in North America (e.g. Bird and O'Connell 2006; Broughton 1994, 1997, 1999, 2002; Broughton and O'Connell 1994; Broughton et al 2011; Butler 2000; Butler and Campbell 2004; Cannon 2000; Grayson and Cannon 1999).

While it has yet to be used to explain subsistence change during the Laptia expansion in any great detail, HBE has been applied to quantified studies of later periods of prehistoric human foraging during colonization in eastern Polynesia, specifically in conjunction with archaeofauna from New Zealand (Allen 2012; Anderson 1973, 1981; Nagaoka 2000, 2001, 2002a, 2002b, 2005), Cook Islands (Butler 2001), Hawaii (Morrison and Hunt 2007) and on Tokelau in western Polynesia (McAlister 2002). Its successful application attests to its strength in deduction by predicting subsistence behaviour adaptation within ecological patches using OFM which can be tested in the archaeological record (Nagaoka 2002, Winterhalder 1981, Smith 1991, Stephens and Krebs 1986).

### *4.2.2 Applying Optimal Foraging Models (OFM) to the Teouma archaeological record*

HBE relies on OFM to test if foragers make optimal subsistence choices by measuring changes in foraging efficiency (Bayham 1979; MacArthur and Pianka 1966; Winterhalder and Smith 1981). OFM have been successfully used to predict what resources foragers will use over time and space and how subsistence will change in response to declining resources (Nagaoka 2002: 422). OFM predict that foragers choose which taxa to pursue so as to maximize foraging efficiency and improving factors of natural selection that ensure survival. The OFM used to predict subsistence change at Teouma using archaeofauna datasets and outlined here include the Prey Choice Model, Patch Choice Model, Diet Breadth Model, Marginal Value Theorem, and Central Place Foraging Model. But to operate OFM, a set of components, with inherent assumptions need to be evaluated and defined. These include a goal, a set of strategies, a currency, and a set of constraints (e.g. Krebs 1978; Smith and Winterhalder 1992:50).

In ecological (Bayham 1979; Charnov et al 1976; Griffiths 1975) and ethnographic (Hames and Vickers 1982, Hawkes et al 1982, Johnson 1983) studies, these sets of operation rules applied to OFM can be measured as single events and the foraging behaviour observed directly, making their results more reliable. However, because of the nature of zooarchaeological data, OFM cannot be applied directly and must be adjusted and more assumptions need to be made (Grayson and Cannon 1999). Zooarchaeological data rarely reflects single foraging events but rather a cluster of subsistence events by an unknown number of participants (Winterhalder and Smith 2000). Archaeological deposits typically consist of time averaged units of multiple behaviours typically calculated by imprecise radiocarbon dates and relative cultural sequences (see Chapter 3 for details of Teouma spatio-time averaged temporal units). As a result some of the components remain unknown and difficult to measure using archaeological data. Fortunately OFM are useful because they provide generality in that these four components (goal, strategies, currency, constraints) can be quantified or qualified in a flexible manner suitable to archaeofauna (e.g. Broughton 1994, 1999; Nagaoka 2000).

Applying OFM to answer questions of Vanuatu subsistence change requires understanding of these components and adjusting them to the requirements of the Vanuatu data. This is addressed below where OFM have been adjusted to explain models of Lapita mixed economy (see Chapter 2) and each component is explained within this context.

### *4.2.3 OFM Components*

The *goal* of Lapita and Post-Lapita settlers is assumed here to be protein/fat maximization. Essential nutrients including protein, fats, carbohydrates, minerals, and vitamins are required for a healthy diet, with protein, fats and carbohydrates providing the energy (Whitney and Rolfes 1993). Complete proteins contained only in animals are even more essential to the human diet because of the amino acids they provide to build and maintain body structure (Wing and Brown 1979:46). Ethnographic studies have found that given a choice, hunter gatherers make decisions to maximize protein typically gained from hunting rather than carbohydrates typically gained from agriculture or gathering (Keegan 1986). But it is considered here that because of the high energy gained from animal fats (Wing and Brown 1979) and the need to balance the diet to avoid protein overload which cannot exceed 30% of dietary intake (Noli and Avery 1988), fat should be considered of potentially equal importance when making rational subsistence decisions. Assessing prehistoric carbohydrate diet content from plants, which would somehow require the integration of archaeobotanical and stable isotopic data with archaeofauna data, is beyond of the scope of this project.

A detailed set of *strategies* that define the options that Vanuatu prehistoric inhabitants may have used to acquire protein/fat is important including capture methods and technology, although limits set by archaeological records make this difficult. Changes in technology have been determined from artefact materials associated with faunal deposits (e.g. Allen 1992a, 1992b) or by measuring changes in harvesting techniques with fauna organized by capture method (McAlister 2002; Butler 2001). Broad strategies can also be inferred from ethnographic and historical records. For example, Lapita fishing technology is well known to have been varied and generalized and likely included nets, hooks, lures, spears, traps and poison (Butler 1994; Green 1986; Kirch

and Dye 1979) to allow exploitation of a range of marine habitats. Beyond that very little is known about Lapita hunting technology, apart from Neolithic stone and shell tool making technology and seafaring transport. Technological changes are not apparent at Teouma based on artefactual material nor were any taxa within any of the resource patches able to be organized by any clear capture method. Therefore changes in technology are not likely to be a factor in changes in faunal relative abundance over time.

An understanding of what prey were available and where they were distributed across the landscape is also essential so that prey can be ranked and distributed in resource patches for the purposes of operating the Prey Choice and Patch Choice models. This can be difficult, based on location, considering some animals can be found in more than one patch, creating overlap issues for interpretative ecological models (Broughton 1999; Cannon 2000). Understanding capture methods is also fraught with assumptions in archaeological optimal foraging studies, with some taxa able to be captured in multiple ways and capture techniques can usually only be inferred from the archaeological data (e.g. Allen 1992a; Nagaoka 2000). In some cases prey characteristics or hunting techniques are used to group prey into patches (Keegan 1986; McAlister 2002; Smith 1991; Stiner et al 2000).

OFM require a *currency* that prey rankings are based upon in order to estimate the relative return rates of each individual species minus the cost of search, capture, and processing costs (Nagaoka 2002: 422). Because the goal is maximizing net returns of protein and fat, prey need to be ranked based on how much protein and fat they contain minus these costs. These costs are often calculated in ethnographic and ecological studies but because behaviour in the archaeological record is not directly observable these costs are highly variable and difficult to estimate (Bayham 1979) and so are not attempted here. Ideally one would need to measure the protein and fat ratios of animals and then rank them based on their average protein/fat content. However, measuring the precise protein and fat content value of each animal is beyond the scope of this study and any results could be plagued by inherent error due to interspecies variation, and the inability to elucidate these data directly from extinct fauna.

Due to these issues, prey body size has been used as a proxy to measure post-encounter return rates to apply to archaeofauna data (Bayham 1979; Broughton 1994, 1999;

Broughton et al 2011; Butler 2001; Griffiths 1975, Nagaoka 2001, 2002a, 2002b). Prey size has been positively correlated with post-encounter return rates (Morin 2011) due to a combination of large meat packages and economy of scale reductions of costs per individual prey. It is assumed here that the larger the prey the greater the protein and fat content and the higher the post-encounter net return rates on offer. This method has come under some criticism (e.g. Bird et al 2009; Bird and O'Connell 2006) based on its applicability to measure relative return rates between taxa based on size. Examples of smaller taxa which can be located quickly, captured en mass and then processed rapidly with low energy costs per specimen (e.g. the capture of small fishes with nets, bats caught en mass in caves or insects from nests) can often result in extremely high rates of foraging efficiency despite their smaller size relative to the largest prey (Lupo 2007; Madsen and Schmidt 1998; Ugan 2005). As a result in some cases the largest taxa may not have the highest return rates. For the purposes of this study calculating the relative return rates from potentially mass captured taxa to other taxa is considered to be too problematic, although it is good to be aware of this aspect when interpreting the data.

*Constraints* are limits placed on foraging strategies and they can be external (extrinsic) or internal (intrinsic) (Winterhalder and Smith 2000). Extrinsic constraints in Vanuatu would include island size, elevation, climate, and biogeographic distribution of fauna within varied habitat zones, which vary from North to South (declining biota diversity southwards) and intra-island ecological variation (see Chapter 2). Intrinsic constraints would include cultural practices and beliefs as well as physical predispositions such as possible susceptibility to diseases like gout found on some of the Teouma skeletons (Buckley 2007; Buckley et al 2008). Given the relatively small size of most islands in the Vanuatu archipelago, its high inter-island visibility and the rapid speed that canoe transport could provide may allow mobility of settlement and foraging behaviour. These factors could serve to reduce travel costs as a constraint initially providing high foraging efficiency. But the defined limits of islands could mean that resource depletion as a result of human settlement has the potential to occur more rapidly.

## 4.3 Predictions of subsistence change at Teouma using OFM

Now that the components have been broadly defined and the parameters for the model set out, general application of the models adapted to predict prehistoric subsistence

behaviour over time and space at Teouma is outlined here based on ecological information established in Chapter 3. Most OFM studies are applied to large game hunters from continental non-colonizing contexts (Broughton et al 2011). Thus adjustments are required for a colonizing Pacific Island settlement to account for mass native species extinctions and the inclusion of introduced domestic and commensal animals.

At the heart of OFM subsistence change predictions is resource depression and resource intensification as prey encounter rates and foraging efficiency decline (Charnov et al 1976). As this happens, greater amounts of energy must be expended to maintain or increase resource output in order to sustain potentially growing populations (Broughton 1999). Resource depression and intensification is considered an important factor in behavioural changes in human prehistory as subsequent subsistence change has been temporally linked to changes in technology, division of labour, material culture, warfare, declining health, settlement patterns and the emergence of agriculture, social stratification and social inequality (e.g. Bird and O'Connell 2006; Broughton and O'Connell 1999; Broughton et al 2010; Cannon 2003).

In particular two sets of predictions about subsistence change can be made using OFM (Nagaoka 2000). The first set of predictions involves the use of the fine grained Prey Choice Model combined with the coarse grained Patch Choice Model (e.g. Broughton 1999) to predict what prey types are selected for exploitation within a patchy resource environment. The second set of predictions focuses on the subsistence decisions at the individual prey level using the Central Place Foraging Model and the Marginal Value Theorem. These models predict foraging responses to resource patch depletion and increasing distance related costs resulting in lower foraging efficiency. Responses typically include intensification of resource utilization and central place butchery and transport decisions (Orians and Pearson 1979). These predictions suggest a continuously changing set of net return rates, which humans must adapt behaviour to so that ecological interactions are carried out in a rational economic way.

### *4.3.1 Prey Choice and Patch Choice Model predictions*

The Prey Choice Model directly links human behaviour to ecology by predicting which prey will be selected as a result of random searching throughout a fine grained homogeneous environment (see Broughton 1999; MacArthur and Pianka 1966; Smith 1983, 1991; Winterhalder and Smith 1992 for a review of both Prey Choice and Patch Choice models). It predicts that foragers will select prey with the highest return rates when encountered to maximize foraging efficiency under selective fitness. It is also predicted that this causes resource depression as high ranked prey encounter rates decline resulting in ecological modifications as a result of human foraging behaviour over time (Broughton et al 2010). Typically it is predicted that when high ranked prey are depleted then diet breadth will expand to incorporate lower ranked prey over time (e.g. Nagaoka 2002: 86), while diet is expected to become broader and more evenly spread over a wider range of resources as foraging strategy becomes more generalized (McAlister 2002). This usually represents a decline in foraging efficiency as marginal returns decline and a wider range of lower ranked taxa are added to the diet.

At Teouma the Prey Choice Model predicts that Lapita foragers would initially specialize on hunting high ranked large game reptiles including giant tortoises, sea turtles and crocodiles, resulting in resource depression and declines in encounter rates and foraging efficiency followed by a dietary shift towards lower ranked taxa. Prey encounter rates for initially abundant naïve avifauna and fruit bats could also be expected to decline as a result of hunting, habitat loss from deforestation (a consequence of horticultural development) and invasive introduced mammals resulting in their rapid decline and extinction of some species. The Diet Breadth Model could then be expected to narrow with fewer species available although a more even and generalized focus on a wider range of resources can be expected in response to resource depression, extinction and intensification.

However, the problem with the Prey Choice Model is that it must assume that prey are randomly distributed within a homogeneous environment, which in reality is not the case. This is because animals tend to cluster in specific habitat patches where they have adapted feeding behaviour (e.g. Broughton 2002). The Patch Choice Model is often used in combination with the Prey Choice Model to study how patches are exploited and how much time is spent foraging within each resource patch (Nagaoka 2000). Typically this works by using the Prey Choice Model to predict subsistence decisions within a heterogeneous patchy landscape using the Patch Choice Model. This is done by

linking ranked taxa to specific resource patches, not always an easy task when some taxa can be present in a number of patches (Broughton 2002). Each patch is ranked by average net return rates (Benefits minus costs) within each patch to determine which patch is selected for exploitation (Smith 1991). It is assumed that foragers have perfect information on the structure and average return rates of each patch so that they make decisions based on this information accordingly (Smith and Winterhalder 1992). When efficiency gains are possible, new or additional resource patches can be exploited. Conversely a resource patch is predicted to be abandoned altogether when it has suffered resource depression to the point where marginal net return rates fall below the average net return rates for all patches.

In Chapter 2 it was discussed how Lapita economies were typically comprised of mixed foraging and horticultural economies. This creates an issue when it comes to the application of HBE models, which typically predict prehistoric hunter gatherer behaviour. One of the problems is that horticulture and animal husbandry within OFM violates the assumption that resources are foraged for randomly within a resource patch (Nagaoka 2000). However, OFM have been applied directly to mixed economic systems in actualistic ethnographic studies and prehistoric dietary reconstructions (Barlow 2002, 2006; Barlow and Metcalfe 1996; Diehl 1997; Gage 1980; Hawkes et al 1982; Johnson 1983; Keegan 1986; Simms 1987) by calculating all the costs and benefits of all resources both foraged and produced. Food production issues within OFM can be reconciled, as Keegan (1986: 95) argues, by conceptualizing horticulture associated resources as "managed patches" within the context of the Patch Choice Model and subject to different costs and benefits compared to hunting and gathering in other patches. The main difference is that search time costs are considered the labour time required to produce the food. If pigs are closely managed then pursuit costs should be zero, but costs are incurred in other ways during pig management. In fact the costs and benefits have been more comprehensively studied for pigs than other taxa in the Pacific with a number of key costs and benefits quantified, although these studies vary to some degree (see Hide 2003 for a review) and for the sake of simplicity such a detailed study is not attempted here.

The costs of pig production can be very high and under certain circumstances pigs are generally considered an expensive way to convert carbohydrates into protein and fat based on increasing labour costs for increasing pig production (See Rappaport 1968;

Oliver 1989). If pigs are being utilized for meat as the primary motivation then pig production should be managed at a level that incurs the least costs when wild taxa ranked higher than pigs, based on net protein and fat returns, are available. An ethnographic example of a typical traditional non-intensive system are free range pigs that are kept domestic by regular feeding, but otherwise forage for themselves for the bulk of their diet (see Hide 2003; Rappaport 1968 ). This involves hand feeding pigs food (mostly tubers) unfit for human consumption, enough to keep small numbers of domesticated pigs while they forage for the rest of their food. This requires little extra food production and associated labour costs. Typically, ethnographic accounts have reported that this results in a village demographic pattern of mostly young pigs under the age of two years during short term pig management cycles (Hide 2003). More intensive production of pigs for meat, which may require additional labour inputs, should only occur when higher ranked taxa from other patches are depleted to the point where net returns from pig production are higher as predicted by the MVT (Charnov 1976), but adapted to incorporate produced resources. Another option is that if the cost of pig production becomes too high relative to other protein and fat resources, pig husbandry could be abandoned altogether, as has happened on a number of Pacific islands and usually attributed to a range of environmental, economic and cultural factors (Bay-Peterson 1983; Clark et al 2013; Giovas 2006; Hide 2003). Alternatively if wild pig abundances are high the most optimal procurement of pigs would be to simply hunt them and there are many ethnographic examples of pig hunting in Vanuatu (Deacon 1934; McIntyre 1997).

As is the case with hunting where search times increase as prey get harder to find, in gardens productivity declines with time as soils become degraded and the encounter rate of crops and domesticate/commensal animals decreases with each harvest. Keegan (1986) in particular used a combination of ethnographic data which calculated currency units of calorie and protein yields of crops and prey targeted from three resource patches (forest, river, garden), as well as costs expressed in time from searching, handling and processing. A similar approach was suggested by Nagaoka (2000, 2002) touching on using OFM, very briefly, to predict changes in the exploitation of domestic dogs by Maori at the Shag River Mouth site in Southern New Zealand during the Archaic period of Maori settlement.

Following on from these suggestions in the literature, for this project, prey is ranked within three general, and largely non-marine, resource patches where these taxa are most likely to be found in abundance (Figure 4-1). This reduces problems with overlap of certain species within variable patchy habitat zones. These resource patches determined from identified Teouma taxa (see Chapter 3) include the terrestrial patch, coastal patch and the domestic patches to include both wild animal foraging and domestic animal exploitation within the Patch Choice Model. The terrestrial patch consists of giant tortoise *?Meiolania damelipi* and *Crocodyloidea* as the largest and highest ranked taxa, although their relative size is not known for certain. Being the smallest taxa, land and aquatic birds, of various medium to small sizes, and fruit bats occupy the lowest rank. The coastal patch is represented by sea turtle and coastal birds only, with sea turtle being the highest ranked taxa in this patch. The domestic patch is comprised of introduced domesticated and commensal animals including pig, chicken, New Guinea Spiny rat and the Pacific rat in order of ranking by size. Despite the generality of this approach there are still issues that one should be aware of.

Extinct species such as the Vanuatu giant tortoise or taxa identified to a high level such as *Crocodyloidea* have uncertain ecological designations. Both are expected to be found within a coarse terrestrial environment. Salt water crocodiles could be found in coastal or marine environments but spend most of their time in inland terrestrial and coastal estuarine rivers mangroves and lakes. The Patch Choice Model also indicates that prey may not be randomly distributed in a homologous patch because the terrestrial patch is comprised of many habitats. For example the terrestrial patch could consist of wetlands, tropical lowland forest and tropical elevated rainforests. Many of the bird species and giant tortoises could occupy all of these habitats or favour only a select few. A number of sea birds could potentially be found in inland wetland environs. Sea turtles can be found concentrated in nesting colonies on coastal beach locations or in feeding grounds around the inshore reef. Capture in these different locations is very likely to involve differential costs, encounter rates and thus return rates (Bliege-Bird and Bird 1997:54). There are also some problems with the structure of taxa within the domestic patch. For instance in some cases pigs are not managed and feral populations are recorded as being hunted in forests across the Asia-Pacific including Vanuatu (Deacon 1934: 192; Hide 2003). Rat predation also varies across cultures in the Pacific and the difficulty in determining predation from natural mortality in the archaeological record makes patch

designation difficult. In addition their distribution in island ecologies could vary from close to site in disturbed garden environments or within various forest habitats.

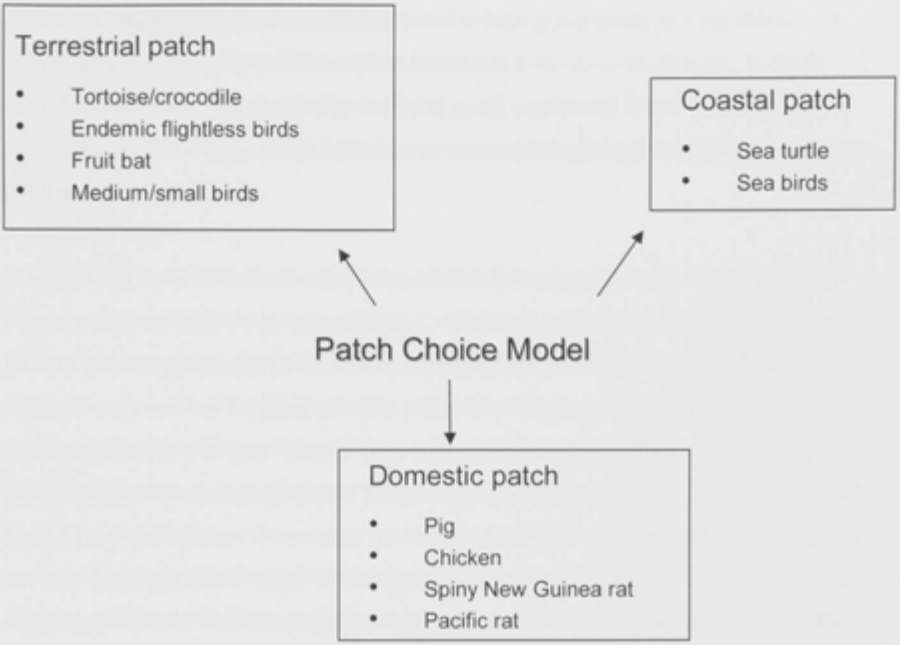


**Figure 4-1: The Prey Choice and Patch Choice Model applied to Vanuatu archaeofauna assemblages, taxa ranked by size in each resource patch.**

It is predicted here that the coastal and terrestrial patches would initially have the highest net marginal return rates available to Lapita colonists and it is therefore predicted that the most time would be spent foraging there. Large mega-fauna tortoises, which have reached extremely dense biomass elsewhere (Coe et al 1979:163), would have provided the highest returns. Tortoises would always have been taken when encountered. Large bodied sea turtles would have also been initially available in the coastal patch in potentially dense concentrations on a seasonal basis at specific beach nesting locations, as well as on or near the reef edge at feeding grounds in much smaller abundances. The marine patch, including fish and shell-fish taxa, is likely to yield a significant biomass exceeding the terrestrial and coastal patches in average net return rates, but is not included in this study. Problems in estimating the costs of food production in relation to costs incurred from hunted taxa make it difficult to rank terrestrial and coastal resource patches in relation to the domestic patch. It is assumed

that the increasingly higher marginal labour costs from pig husbandry (see Hide 2003) would make pig production less optimal when wild prey are available in abundance. It should also be considered that initially Lapita colonists would have taken some period of time to establish gardens and domesticated animal populations and therefore subsistence at Teouma would have been structured more towards foraging to begin with. It is predicted here that in the domestic patch, traditional low level animal husbandry could be expected to keep labour costs and declines in foraging efficiency to a minimum.

A significant issue with the Patch Choice Model is that it doesn't take into account resource depression from human activities, which can combine to reduce the net return rates of patches and so the MVT was developed (Charnov 1976). The MVT has a suggestive element of foraging mobility and deals with resource depression by understanding how foragers should cope with changing prey abundances within a patchy environment. It predicts that foragers will leave a patch when the net return rate for the patch falls below the average net return rate for all exploited patches taking into account distance related travel and transport costs between patches (Charnov 1976). If foraging efficiency declines in depleted resource patches and net return rates fall below the average patch return rate, new resource patches with return rates higher than the average will be exploited while depleted patches may be abandoned. MVT predicts that decisions on which patch to exploit is dependent on when net returns from a single patch fall below average return rate from all patches. As these return rates are constantly changing the average return rate can be inadequate for each patch and variation within each patch makes these calculations difficult to control (Keegan 1986:98).

Previously it was detailed how the Patch Choice Model predicted that time would initially have been focused on foraging within the terrestrial and coastal patches at Teouma due to higher return rates and foraging efficiency. The MVT predicts these resource patches would become depleted until an ecological tipping point is crossed at a certain point in time. At this point other niche patches within the broad terrestrial patch may also be added to the foraging schedule as more resource specific patches become depleted. Alternatively, when the net returns from domestic animal management compares more favourably with net returns from other resource patches, it is predicted that pig production will intensify. In other words meat production will only increase when wild faunal resources became depleted at a certain point below average net returns

for all patches. Overall foraging efficiency should decline as a result of increased labour inputs and resource intensification within the domestic patch. Considering the high costs of intensive pig production associated with traditional pig husbandry methods, there would have to be a drastic reduction in wild animal resources before increasing pig production intensity became more efficient than foraging. Conversely if wild taxa abundances were to increase then we could expect to see a decline in pig production relative to terrestrial and coastal patch resources. This fits in well with Midwest American studies which saw a shift from intensified agriculture to low intensity shifting agriculture and big game hunting after migrating large mammals suddenly became available, enabling an increase in foraging efficiency (Barlow 2002).

The predicted implications of resource depression and resource intensification on economic transitions to agriculture outlined above have been demonstrated in other studies (Hawkes and O'Connell 1992, Madsen and Simms 1998). Measuring this transition is difficult but eventually the ability to quantify prehistoric agricultural intensification based on marginal costs and benefits applied to zooarchaeological data will become possible (Phillips, Jr 2009). Domesticated food resources tend to be more labour intensive than foraged foods (Barlow 2002; Keegan 1986; Philips, Jr 2009) and an increasing intensity of pig production indicates an increase in search time costs in the domestic patch, resource intensification, and lower efficiency as more time spent in the domestic patch is needed to increase the yield. This should be manifested in the Oceanic zooarchaeological record by increased quantities of pig remains, a more narrow range of pig ages being exploited, while isotope signatures from pig bones should also reflect increasing reliance on crops over time as a proxy for agriculture intensification (e.g. West 2007). Pig skeletal element representation should become broader and more intensively butchered to the point where the frequency of butchery increases in intensity as more time is spent processing the carcass. This should be accompanied by growth in settlement size.

### *4.3.2 Prey utilization and Central Place Foraging predictions of subsistence changes*

The Central Place Model (Orians and Pearson 1979) is also combined with the MVT to predict in more detail how long foragers spend in each patch by investigating individual

large-bodied prey utilization. It deals more directly with the issue of forager mobility to exploit different resource patches from a central place and the need to factor in distance related costs of travel (Cannon 2003; Grimstead 2010; McGuire et al 2007; Metcalfe and Barlow 1992; Nagaoka 2000, 2005b; O'Connell et al 1988). They predict that foragers will spend less time in a resource patch if its net return rate falls below the average return rate for all exploited patches taking into account the costs of moving to another patch and predict more time spent foraging in higher return patches (Charnov 1976). OFM predict two alternative foraging responses (butchery and transport decisions and intensification of animal processing) to reductions in foraging efficiency due to declines in encounter rates of large bodied taxa. Which response is chosen depends on distance related costs, which will result in changes in how individual prey will be utilized, (e.g. Broughton 2002; Nagaoka 2005b).

If prey are targeted at a constant distance from the site, the MVT (Charnov 1976) predicts that as resource depression of large bodied high ranked taxa occurs then intensification of time allocation within a patch will only increase over time as more time is spent processing each individual carcass. This intensification of prey exploitation could result in an increased utilization of animal body portions with lower nutritional value and thus a broadening of skeletal elements returned to the site over time. It could also result in increasingly intensive processing of each animal body portion reflected in higher rates of butchery over time (e.g. Nagaoka 2000).

Alternatively the Central Place Foraging Model predicts that as proximal resources become depleted resulting in an expanding depleted zone, its magnitude depending on the size of the population and distance, distance related costs becomes a crucial factor (Metcalfe and Barlow 1992; Orians and Pearson 1979). As targeting large prey in distant patches start to increase, the MVT predicts foraging efficiency will decline sharply (Grimstead 2010; Metcalfe and Barlow 1992). Mobile distant foraging is predicted to result in decisions that minimize these distance related costs. In this case the model predicts that as foragers move further afield into more distant resource patches, they will target high ranked large bodied prey on encounter. This will result in the relative proportions of high ranked taxa to increase again after initial declines from resource depression (e.g. Broughton 2002:70). It also raises issues of maximization in the face of constraints placed upon how much a forager can carry resources back to base. When this happens then transport costs will increase and decisions on field

processing of individual animal carcasses will be made to discard low nutritional utility animal body portions while transporting high ranked body portions back to the site to improve foraging efficiency (e.g. O'Connell et al 1988; Metcalf and Barlow 1992; Nagaoka 2005b).

Both strategies, intensification of prey utilization and central place foraging, are likely to have been played out by Lapita foragers at Teouma as relative net return rates are likely to have fluctuated in response to human induced changes in ecological conditions within various resource patches over time. The MVT predicts that as terrestrial and coastal patches close to the Teouma site are depleted, prey carcass utilization of high ranked reptiles would intensify as more of each individual animal is utilized. Alternatively, foragers would target high ranked reptiles in similar resource patches further away in increasing numbers, transporting back only the most nutritious body parts to reduce transport costs. The Central Place Foraging Model and MVT predict that whichever strategy has the highest net return rate at any given point in time and space will be chosen.

Initially mobility in the Vanuatu archipelago may have been greater while regional population density and transport costs are likely to have been low through the use of seafaring craft. The use of central bases from which to exploit these resources may not have been necessary, but the establishment of permanent settlements appears to have been a priority at sites such asTeouma. Over time mobility can be expected to reduce as regional population densities increase and resource depression spreads outwards. Over time we should see changes in proportions of relative abundance of high ranked and low ranked taxa in each resource patch. Settlement patterns should comprise stratified sites as humans use a central site as a base. At this point after periods of resource patch intensification the lower ranked resources should become dramatically depressed, with possibly declining densities of faunal remains and a sharp decline in small prey ages over time. At this point it is likely that the costs of relocating a settlement may become less of a factor as higher marginal return rates in a new location with more abundant resources become a significant pull factor (e.g. Nagaoka 2000).

## 4.4 Incorporating costly signalling theory into the framework

A fundamental criticism of evolutionary theory is the difficulty explaining culture change because human agency is not simpatico with an extreme cultural materialist deterministic approach. It simply does not take into account ideological and religious beliefs (e.g. Hodder 1986; Shanks and Tilley 1987). Ingold (2000) regards behaviour as being linked to culture and not genes developing out of historical contingency or social learning while culture limits optimality. Humans are capable of a range of behaviours and may choose food for its prestige or symbolic value rather than maximize net energy return and high foraging efficiency. Some scholars argue that before capitalism, human societies employed satisficer or 'good enough' strategies (see Ward 1992) where they exploited just enough food to meet minimum dietary requirements, rather than maximize energy returns, so they could focus more on social values. From an evolutionary standpoint there are other non-economic ways for individuals in society to maximize reproductive fitness. This can also be achieved by increasing social status to gain access to mates to ensure reproduction or improving inclusive fitness through altruistic behaviour for the good of the group to increase the chances of their genes being passed on to future generations. The view amongst behavioural ecologists is that people tend to select behaviour from a range of options which are most optimal to increasing individual reproductive or inclusive fitness (Kelly 1995). For these reasons some archaeological researchers have incorporated human agency into their evolutionary models for how societies evolve (e.g. Earle 1980; Earle 1987).

OFM researchers are aware of variation in human behaviour that can affect foraging efficiency independent of optimization and have incorporated alternative interpretations of OFM data including changes in harvesting techniques and technologies (Butler 2001; Janetski 1997; Madsen and Schmitt 1998), social complexities (Bliege-Bird and Smith 2005; Hawkes et al 2002; Hildebrandt and McGuire 2002; McGuire and Hildebrandt 2005; McGuire et al 2007; Smith and Bliege-Bird 2000; Winterhalder 1986), and shifts in gender labour division (Kuhn and Stiner 2006; McGuire and Hildebrandt 1994; Elston and Zeanah 2002). These can all affect relative taxonomic abundances.

Social political complexity is often considered the evolutionary adaption of strategic decision making and social behaviour such as food sharing or meat distribution during funeral rites, big game 'show off' hunting or 'big-man' feasting (Hawkes et al 1993;

Hildebrandt and McGuire 2002). These are all aimed at gaining prestige and social influence for increased reproductive fitness and these social theories have been recently combined with evolutionary ecology into a single theory known as costly signalling (Bird and O'Connell 2006; Bliege-Bird and Smith 2005; Hawkes and Bliege-Bird 2002; Hildebrandt and McGuire 2002; McGuire and Hildebrandt 2005; Smith and Bliege Bird 2000). Signallers communicate their intrinsic value to a social group through elaborate and expensive displays. While others argue that the ethnographic and archaeological evidence indicates that these factors are over inflated by these researchers when interpreting OFM data (Broughton and Bayham 2003; Codding and Jones 2007) the utilization of some animals at Teouma to demonstrate social ranking by costly signalling is likely. This is especially so considering the generalized signs of social stratification and ritual where decorated pottery and shell jewellery are associated with varied burial practices during the Lapita use of the cemetery (Bedford et al 2010).

Fluctuations in big game hunting have been attributed to changes in prestige hunting for periodic social feasting (Hildebrandt and McGuire 2002) and this perspective could be attributed to fluctuations in reptile hunting at Teouma. Examples of using animals for costly signalling in the Pacific, which may be applicable to this research, include 'show off' hunting of green turtles on their feeding grounds near the reef edge like Torres Strait where hunters gain prestige due to the difficulty and danger of hunts or their use in food distribution or funerary rites to signal social status (Bird and Bliege-Bird 1997; Smith and Bliege-Bird 2000). Fluctuations in large game versus small game foraging could also be attributed to gender divisions of labour or divisions in gender specific diet as indicated from stable isotope studies on Teouma Lapita skeletons (Kinaston 2010).

Some food resources may not be intrinsically valued for the meat they can provide but more because they are rare and costly to produce. This makes them highly sought after and, therefore, represents symbols of social status and power for those individuals who possess them. For example the very rare intersex circular tusk pigs in northern Vanuatu demonstrate wealth and chiefly power through costly social-ritual (McIntyre 1997; Harrison 1937; Deacon 1934; Bonnemaison et al 1996). In the Prey Choice and Patch Choice model predictions section it was predicted that pigs would be optimized in the diet by being managed or hunted in the least costly method possible to maximize net energy returns. Here an alternative possibility in pig husbandry is predicted where pigs are managed in the most costly fashion for the purpose of signalling the wealth of

Lapita and Post-Lapita elites through feasts in a similar fashion to ethnographic examples of circular tusk pigs mentioned above. Such social hierarchies based on pigs, prevalent in northern Vanuatu today, appear to be quite recent and dating to the last 600 years only (Garanger 1972).

The above examples are all possible alternative social interpretations of zooarchaeological data derived within evolutional models. But unlike rational subsistence economic behaviour, social-political aspects of human animal utilization remain difficult to directly quantify in the archaeological record. However, direct archaeological evidence can be qualified within the Teouma vertebrate assemblages. Taxa that do not appear to be optimal prey choices or desired food items may be valued for their intrinsic or social values and may suddenly appear in a temporal unit. Some animal materials may be fashioned into functional or stylistic artefacts to be used as tools or displays of social status. Each artefact is likely to be shaped for an intended function by a human individual from some mental construct incorporating symbolic elements based on learned or personal social values (Read and van der Leeuw 2008). Interpreting that intended function is often impossible from archaeological data. However, for the purposes of this study such items made from bone would represent the presence of social values in animal acquisition rather than just protein optimization.

## 4.5 Summary

This thesis aims to use zooarchaeological methods to analyse the Vanuatu faunas within an evolutionary ecological theoretical framework. This allows a deductive approach to understanding resource depression and subsistence change in prehistoric Vanuatu. It is argued here that human subsistence change is likely to have been a complex fluid process of decision-making, influenced by rational economic choices and cultural values or beliefs within the context of changing ecological and environmental conditions. The research was designed accordingly to test optimal human subsistence behaviour using a set of predictions from OFM that operate as laws observable in the archaeological record. Cultural values, while not equally quantifiable as optimal values, could potentially be reported in association with subsistence changes and so these alternative socio-cultural alternatives are built into the research design. A number of

predictions of optimal foraging and cultural demonstrations of wealth and power have been detailed above, along with their predicted archaeological signatures.

# 5 Analytic Datasets and Procedures

In this chapter I discuss the zooarchaeological datasets and procedures necessary for testing OFM and costly signalling predictions for Teouma subsistence change generated in the previous chapter. Each prediction for a general set of optimal and non-optimal behavioural 'rules' has a predicted archaeological signature explicitly linked to ecology or culture. Multiple lines of zooarchaeological datasets are typically used in evolutionary frameworks to measure changes in foraging efficiency to test OFM predictions of subsistence change (Broughton et al 2011). It is the strength of the theoretical framework to develop very detailed methodologies focused on a clear purpose. Datasets used in this study measure changes in prey diversity (Diet breadth and evenness) and relative abundance (Abundance Indices), skeletal element representation, prey demography, and intensification of individual prey utilization. They provide very fine detail on dietary changes, the quality of palaeohabitats exploited, resource depression, mobility and changes in intensification of resource patch utilization. These datasets and procedures detailed below were used to analyse reptile, mammal, and bird remains. Shellfish and fish remains were not included because of the sheer size of the assemblages and the need for realistic achievable goals within the time frame available.

## 5.1 Prey diversity

OFM predict changes in prey diversity in response to resource depression, which indicates changes in foraging efficiency. Two measures of prey diversity are used here; diet breadth, which is a simple measure of the number of taxa exploited; and equitability or evenness, which takes relative abundances into account. They both indicate foraging behaviour that falls within a dichotomy of generalized or specialised foraging strategies. Generally a more specialized focus on a few high ranked taxa indicates high foraging efficiency, while conversely the expansion of the diet to a generalized broad range of lower ranked taxa indicates an overall decline in foraging efficiency.

### *5.1.1 Diet Breadth*

The Diet Breadth Model predicts that as foraging efficiency declines due to resource depression of high ranked taxa, diet breadth (NTAXA) should expand (e.g., Nagaoka 2001). This is a simple and effective way to indirectly measure changes in foraging efficiency by measuring how many taxa are being exploited over different time periods (NTAXA per temporal unit). A decline in abundance of high ranked taxa should decrease the average net return rates to the point where NTAXA increases as lower ranked taxa are added to the diet. By implication declines in foraging efficiency usually follow. However, NTAXA can be inflated by foraging events that include random increases in small quantities of a wider range of taxa, which may not reflect the average foraging behaviour (Grayson and Delpech 1998).

### *5.1.2 Equitability (Evenness)*

While NTAXA is a simple and effective measure of foraging efficiency it does not take into account the relative proportions of different taxa in the diet so equitability otherwise known as evenness diversity indices can compensate for this (Nagaoka 2001; McAlister 2002). Here the Shannon-Wiener diversity index is used to measure biodiversity where Equitability (E) = $-\Sigma$ (pi ln(Pi))/ ln(NTAXA) (see Grayson and Delpech 1998; Nagaoka 2000). Equitability can measure foraging efficiency indirectly from a shift in uneven prey choice of a few high ranked taxa (specialization) to a proportionately broader, more even focus on a greater range of species (generalization). Values of equitability vary between 0 and 1 with higher values indicating greater biodiversity of evenness or generalized focus of diet on a greater range of species (low foraging efficiency) and lower values indicating uneven specialized subsistence behaviour focused on fewer resources (high foraging efficiency).

Unfortunately equitability values on their own may not measure changing subsistence patterns as they do not take into account the ranking order of taxa (Nagaoka 2000). This is because such evenness may remain constant but subsistence behaviour could be changing as rank orders of taxa exploitation could significantly change. Evenness indexes simply do not take into account what taxa are being exploited and unevenness could just as easily be a result of an uneven specialization on low ranked taxa as a result

of intensification and actually lower foraging efficiency. Alternatively, increases in evenness could actually result in increases in foraging efficiency as the proportions of higher ranked taxa increase.

## 5.2 Relative abundance

Measuring prey choice and changes in foraging efficiency requires an effective way to quantify relative abundance by combining effective quantification methods and abundance indexes (AI) which typically demonstrate quality of ecological foraging over time.

### *5.2.1 Quantification*

During the identification processof taxa and skeletal elements the bones were quantified primarily by Number of Identified Specimen Present (NISP). Each bone, whether it was whole or broken, was counted. Refits were attempted to aid identification. However, more time consuming intensive analysis to refit every bone was not conducted and therefore refits were not included in NISP tallies. Fragmentation is not considered a major problem here because many studies have suggested that, with large sample sizes, NISP tends to track MNI quite closely in terms of the ranking of taxa by abundance (e.g. see Cannon 2001; Grayson 1984 for a discussion on quantification issues). NISP has the advantage of not being aggregated by provenance and providing more adequate sample sizes for statistical analysis. However, NISP has issues particularly problems with variability in fragmentation rates, which potentially account for variation in relative taxonomic abundance studies. The validity of NISP will be assessed by NISP/MNE (Minimum Number of Elements) ratios, although Cannon (2013) has recently suggested that fragment size measurement is a much more effective measure of fragmentation rates. Lower ratios tend to suggest low fragmentation rates, higher ratios greater fragmentation. Ideally rates of fragmentation should not significantly change over time, but if it does this could indicate changes in taphonomic processes incurred during butchery and post deposition rather than changes in diet. MNE was calculated with the help of portion and segment codes where the most frequent portion and side of

each skeletal element was counted from a system developed for Bison faunal studies in Northern America (Todd 1987; Todd and Rapson 1999 website).

### *5.2.2 Relative Abundance*

To overcome the limitations of NTAXA and equitability as measures of foraging efficiency, measures of relative abundance are needed to indicate if there were any changes in taxonomic abundance over time. A simple rank order of taxonomic abundance is useful to demonstrate this, independent of many biases inherent in most zooarchaeological quantification methods summarized in Chapter 3 as it relies on much fewer assumptions (see Grayson 1984).

### *5.2.3 Abundance Indexes (AI)*

Critical to measuring foraging efficiency in OFM is the use of abundance indexes (AI) developed by ecologists (Bayham 1979), which quantify relative abundance of high and low ranked taxa in the formula Sum NISP (High Ranked Taxa) divided by the sum of NISP (High ranked taxa + Low ranked taxa). AI have been used in other zooarchaeological studies to measure changes in foraging efficiency (e.g. Broughton 1999; Nagaoka 2000). A decline in high ranked taxa relative to low ranked taxa would indicate a decline in foraging efficiency as encounter rates for high ranked taxa decline and more low ranked taxa are incorporated into the diet (e.g. Bayham 1979). By measuring the ratio of high to low ranked taxa one could measure changes in the quality of the foraging environment. Declines in foraging efficiency are assumed to be the result of resource depression although other non-foraging related factors including changes in environment, technology and prey behaviour could also contribute (Smith 1991). AI can be used to demonstrate changes in technology which could seriously alter prey choice by decreasing costs of acquisition (Janetski 1997; Smith 1983), usually by linking prey to capture methods (e.g. Butler 2001). Changes in environmental conditions and their influence on prey encounter rates have also been controlled for by using AI to link changes in human interactions with prey within specific environments (Nagaoka 2000).

## 5.3 Skeletal Element Representation

Using the Central Place Foraging Model, two predicted responses to resource depression of large bodied reptiles (tortoises and sea turtles) were made. First of all it was predicted that large bodied reptiles would at some stage during the settlement become targeted with greater intensity. Alternatively it was predicted that large game reptiles may be exploited in resource patches increasingly distant from the site as closer resource patches became depleted. Skeletal element representation is used here to test these two predictions. Below is a summary of the procedures used to measure changes in skeletal element frequency.

### *5.3.1 Quantification*

Skeletal element representation was quantified using common measures of MNE and Minimal Animal Unit (MAU). MNE was calculated from detailed portion codes as stipulated in Chapter 3, using complete elements, proximal/distal + < ½ shaft, proximal + >1/2 shaft, as well as segment codes demonstrating the segment of the portion e.g. proximal +< ½ shaft cranial for fraction summation. The portions get more complicated when trying to describe vertebrae and cranial/mandible fragments as these have a variety of descriptive diagnostic zones, portions and segments. To calculate MNE the most frequent side, portion/diagnostic zone and segment of a skeletal element was counted.

MAU and Percentage MAU (%MAU) are often used to demonstrate patterns in skeletal element representation because they take into account how many elements are present in each individual. They first require the calculation of MAU by dividing MNE for each element by the number of times it occurs in the body (Binford 1978; Lyman 1994). For example if there is an MNE of 10 tortoise humeri, which occurs in the body twice, then MAU equals 5. Each element MAU value is then divided by the element in the assemblage with the highest MAU value and multiplied by 100 to get %MAU so that assemblages with various sample sizes can be compared relatively. This is useful for graphically displaying broad patterns of skeletal element representation for an assemblage which can appear even or uneven.

### *5.3.2 Intensification*

One of the predicted consequences of more time spent harvesting large game reptiles within a single resource patch is an increase in butchery and a broader utilization of individual carcass portions. A broader representation of skeletal elements as well as higher rates of fragmentation, cut mark frequencies, and fractures associated with butchery is expected to reflect this response to a decline in large game encounter rates. Conversely, it is assumed that the commonly practiced containment of sea turtles in Pacific island villages for consumption at a later date once they reach maturity was not a strategy employed at Teouma. Such a practice is likely to produce a similar even pattern of skeletal element representation.

### *5.3.3 Butchery and transport decisions*

It was predicted above using the Central Place foraging Model and MVT that once distance related costs became a factor, as proximal patches became depleted, foraging for large-bodied taxa in distant un-depleted resource patches may occur. As this occurs it is predicted that foragers will make kill-site butchery and transport decisions to reduce high distance related costs to improve foraging efficiency by transporting only high value body parts resulting in an uneven range of skeletal elements returned to the site (Bliege-Bird and Bird 1997; Cannon 2003; Metcalfe and Barlow 1992; O'Connell et al 1988).

A simple way to demonstrate this relationship graphically is using %MAU values for each skeletal element by temporal unit and displaying these values on a bar graph. The skeletal element representation analysis excludes all turtle shell fragments because of problems with quantification with MNE in the absence of morphologically and anatomically distinctive shell portions. While this is useful for visibly displaying broad qualitative changes in skeletal element frequencies between temporal units, it fails to display quantitatively in great detail the butchery and transport decisions from one temporal unit to another.

It was Binford (1978) who first used a quantitative method to measure the frequency of various skeletal parts of large animals from archaeological deposits using MAU. To

quantify the utility of each MAU value, he ranked each skeletal element into a Meat Utility Index (MUI). Ethnographic examples support the validity of ranking the economic utility of various skeletal units (Hames and Vickers 1982) and archaeological studies of this nature have become common place (Broughton 2002; Grimstead 2010; Nagaoka 2005b). Typically they calculate the proportion of low ranked to high ranked body parts, by economic utility, present at a site to determine butchery and transport related decisions to reduce distance related costs and improve foraging efficiency (e.g. Metcalfe and Barlow 1992; O'Connell et al 1988; Nagaoka 2005).

To demonstrate these butchery and transport decisions in a patchy environment in more detail, the construction of food utility indexes for large mammals and birds (Binford 1978; Kooyman 1984; Lyman 1992; Metcalfe and Jones 1988) have been utilised to rank skeletal elements by meat, marrow, and grease content, although Metcalfe and Jones (1988) argue that a meat utility index is a sufficient measure. Food or meat utility indexes are then modified to take into account 'rider' elements which are low ranked skeletal elements that are transported attached to high ranked skeletal elements due to their proximity (Binford 1978).

Such detailed food utility indexes have yet to be established for large reptiles and so must somehow be estimated. To compensate for a lack of nutritional data for skeletal elements/anatomical units, I have developed a method that ranks turtle skeletal elements by estimated economic value. This method makes fewer assumptions by using an ordinal rank of expected meat abundance per skeletal element within three ranked categories of high, intermediate and low nutritional utility. Reducing detailed measures, typical of food utility indexes, to a sequence of three ordinal categories makes it possible to evaluate butchery and transport decisions according to these nutritional criteria. This rank-order method need not be concerned with how much meat is on each element, which likely varies from individual to individual. It also makes interpretation rather simple where the proportion of high ranked, intermediate and low ranked skeletal elements can be plotted for each temporal unit. However, in the absence of quantified data it does have to make assumptions about how elements are ranked by meat content within each category.

The giant Aldabra tortoise whose body contains relatively little soft tissue (38%) compared to other animals (Coe et al 1979: 170) indicates that low utility body parts,

likely to be the head, neck, feet and tail, will less likely show up in archaeological sites. Rather there should be greater proportions of meaty limb bones and carapace skeletal elements associated with the body. For the purposes of this study, high-ranked tortoise skeletal elements are taken to include the pelvic elements (pubis, ischium, ilium), which are un-fused in the Vanuatu tortoise (with the exception of one specimen), the humeri and femora and cervical vertebra. These were all deemed to be the skeletal elements that could be expected to have the highest quantity of meat. Intermediate elements include the lower limb radii, ulnae, tibiae, and fibulae. The lower-ranked elements include the crania, mandible, phalanges, metacarpals/metatarsals, carpal/tarsals and caudal vertebrae which are likely to have minimal meat content. These categories are rationalized from expectations based on varied though consistent rankings of skeletal elements from large-bodied mammals where vertebrae, scapulae, pelves, and upper limb bones, the humeri and femora, are ranked highly (O'Connell et al 1988). While such assumptions seem quite reasonable for ranking tortoise skeletal elements, the un-tested nature of the method makes the results preliminary in their nature. There may also be some contention over some of the high-ranked elements because other skeletal elements may have been ranked higher for reasons other than meat quantity, such as delicacies, raw material utilization and other cultural practices. Such alternative explanations are hard to decipher without reliable ethnographic data, none of which exists for tortoise exploitation.

Sea turtle skeletal element rankings are generally similar to tortoise rankings. Low-ranked sea turtle elements with minimal meat include head, neck, flippers and tail (Bliege-Bird and Bird 1997). As with tortoises, intermediate-ranked skeletal elements are taken to be the lower limb elements of the radii, ulnae, tibiae and fibulae. The only difference between the sea turtle and tortoise skeletal ranking system is the neck (cervical vertebra). These are ranked low for sea turtle based on physiology but highly ranked for tortoises, which have a more substantial neck for grazing foliage, an adaptation sea turtles do not need. Turtle shell fragments were not included in any of the tortoise and sea turtle skeletal element representation analysis because of the difficulty in determining which species they represent, as well as the fragmented nature of turtle shell remains making MNE calculations problematic.

To determine temporal changes in tortoise food utility the proportions of each ranked skeletal element category (high, intermediate, low) are plotted separately on single

scatter-plots by temporal unit. This was done first by ranking the skeletal elements into the three categories of high, intermediate and low utility as discussed above. The MNE for each skeletal element was then converted into MAU. Then the sum of all MAU for each temporal unit was calculated and divided by the number of elements classified in each ranked skeletal element group or NELEMENT (see Tables 8-1 and 8-2 for data used to calculate tortoise and sea turtle meat utility respectively). The high, low and intermediate ranked sum MAU/NELEMENT percentage of each ranked category for each temporal unit was used to determine changes in tortoise and sea turtle body part utilization at Teouma. High proportions of high-ranked skeletal elements indicate either high foraging efficiency due to butchery and transport decisions or low utilization of lower ranked skeletal elements due to abundant high- ranked fauna. Conversely a broader range of ranked elements indicates smaller distance from site or decreased foraging efficiency and intensification of prey utilization. Changes in intermediate-ranked skeletal elements are likely to indicate intensification of turtle carcase utility in response to increasing turtle scarcity when transport costs decline in importance.

### *5.3.4 Costly Signalling: demonstrations of wealth and power*

Measuring skeletal element representation is also useful in indicating potential cultural practices many of which demonstrate displays of wealth such as feasting. In Chapter 4 ethnographic examples of the management of pigs to signal wealth and influence within a traditional island culture were discussed. Here it is reasoned that status gained from feasting rituals or mortuary practices might be demonstrated by differential spatio-temporal distributions of high and low ranked meat packages with regards to Lapita cemetery and midden areas and post-cemetery temporal units.

Utility values for pigs were taken from the unmodified Mean Meat Utility (MUI) for skeletal elements from data calculated in Rowley-Conwy et al (2002) (See Chapter 8 Table 8-7 for data and calculations). Because transport rider elements (Binford 1978) are not likely to be an issue with pig remains at Teouma, the MUI was used instead of the modified FUI (Food utility index) which only includes proximal and distal ends of long bones and excludes the shaft. But in some cases MNE was calculated solely from shafts of long bone elements in some temporal units. By using the MUI, these MNE

long bone shafts could be included without the need to be concerned about the presence of rider elements attached to higher utility value skeletal elements. Only sub-adult to mature adult pig age class remains were included in this study reasoning that the infant and juvenile individuals were smaller meat packages and as such consumed accordingly in a non-optimal fashion. Also it is possible that young pigs were culled for reasons other than meat consumption and may have not been a part of the diet.

To calculate the Mean utility index (MUI) a number of steps are required. First the Minimal Animal Unit (MAU) was calculated for each element. Some skeletal elements were grouped together into anatomical units following Rowley-Conway et al (2002), including the thorax (includes rib, sternum, thoracic vertebrae skeletal elements) and sacrum/pelvis, atlas/axis, metatarsals metacarpals/carpals, tibia/tarsal's and phalanges. In addition fibulae elements, not included by Rowley-Conway in this study, were grouped with the tibia/tarsal anatomical unit. These anatomical units were calculated by taking the single most frequent element within these units by MAU as representative of the whole unit and excluding the skeletal elements with lower values. The next step was to simply multiply the MAU value by the mean MUI value for each anatomical unit/element and then divide the sum of these values (MAU*MUI) by the total adult pig MNE for each temporal unit. Dividing the sum skeletal element meat utility by the total MNE for each temporal unit takes into account the different sample sizes between the temporal units so that it reflects average meat utility rather than total meat utility for each period. The mean value specifically quantifies the range of skeletal elements with high values reflecting high quality meat bearing skeletal elements for consumption and low values reflecting the opposite.

## 5.4 Demographic reconstruction

The reconstruction of animal demography (or mortality) is used here to examine both resource depression of tortoises, fruit bats and rats as a result of forging behaviour, as well as pig husbandry practices within the domestic patch.

### *5.4.1 Resource depression*

While resource depression is assumed indirectly from measures of foraging efficiency outlined in the relative abundances section above, these are only indirect links between resource depression and foraging behaviour. Considering that other natural factors could result in prey declines, a more direct measure is recommended to demonstrate the effects of human predation (Nagaoka 2012). Demonstrating a decline in the average age of prey mortality has been used to more directly link resource depression to human predation in the archaeological record (see Anderson 1973, 1981; Broughton 1997; Butler 2001). Foragers are predicted to target adults because on average, individual prime-aged animals offer more body fat in relation to protein than juveniles and provide greater overall returns because of their larger body size (Stiner 1994:377). Targeting of these larger adults often results in a decline in adult populations and a decrease in average age of prey populations within the archaeological record as a result of resource depression. There are, however, instances where resource depression has been inferred when average prey age has increased or no significant decline in age is noted (Broughton 1999, 2002; Butler 2001). This usually occurs when prey in new un-depleted distant resource patches are targeted in response to the depletion of similar more proximal resource patches. To demonstrate this age/size relationship to resource depression, it requires the ranking of different age cohorts of a prey species. In this study it was possible to age both reptile and mammal taxa although differences in biology and growth patterns required the use of different age estimation methods.

Tortoises being reptiles continue to grow during the course of their lifecycle and so unlike mammals don't offer zones of epiphyseal fusion so demography was estimated using morphometric dimensions which relate directly to body mass and age (Castanet and Cheylan 1979). The most rapid growth of tortoises is in the early years of maturation where exceptional growth has been recorded in the first five years of a tortoise's lifecycle so long as food was plentiful, followed by relatively slower rates of growth with advancing age (Jackson Jr et al 1976). Therefore it is reasonable to expect that tortoise bone size will also strongly correlate to age. Four measurements were taken on a range of long bones including greatest length (M1mm), proximal width (M2mm), and distal width (M3mm) after procedures developed by von den Driesch (1976) for mammals but modified here for turtles. Unfortunately complete tortoise long bones with

complete proximal and distal ends were not frequent in the Teouma assemblage. In this case the most frequently recorded elements were humeri and a fourth measurement (M4mm) was adopted here for the most frequently recorded humeri portion on the upper shaft width just below the posterior proximal fissure (Figure 5-1). This is where the bone happens to be at its densest thus allowing the more frequent survivorship in the archaeological record. Indeed a great range of tortoise bone sizes were observed qualitatively during the identification stages.


**Figure 5-1: Large variation in size of *?Meiolania damelipi* humeri, M4 width (mm) used to demonstrate changes in tortoise size with measurements taken just below the posterior proximal humeri fissure.**

While this method is suitable for estimating age at death for taxa such as fish, shellfish and reptiles that do not stop growing during their life cycle, it is not suitable for mammals which stop growing skeletally once skeletal maturation is reached soon after adulthood is reached. Here mammals, including rats and pigs, do have a number of methods that can be used to assess age of death. These include rates of long bone and vertebra epiphyseal fusion, timetables for tooth eruption, and relative age estimation by tooth wear (see Chaplin 1971; Morris 1972 for a review). These estimations can be expressed as an age range in months and years or as age classes of juvenile, sub-adult and adult after Chaplin (1971).

Prehistoric human interactions with commensal rats in the Pacific have been rather ambiguous and demonstrating prehistoric rat predation by humans has been difficult to do (Colman 1998). A demographic reconstruction of prehistoric rat populations, something which has not been previously attempted, is used in this thesis to link changes in rat mortality to human occupation (see Chapter 7). Fortunately there are well established orders for long bone epiphyseal fusion for the albino rat (Dawson 1925) from which to guide such an exploratory study. There are two general phases of rat long bone epiphyseal fusion making demographic estimations simple to interpret. Early-fusing rat skeletal elements mostly fuse within the first 3 months of a rat's life. Late-fusing skeletal elements start fusing after 1000 days or 33 months. Rats don't tend to live much more than 4 years, therefore the demarcation between juveniles, adults and mature adults is clear. Rat hunting and resource depression could be reflected in increased mortality and a decline in average age over time. However, because they are small and breed rapidly they are likely to recover from such events quickly, possibly too quickly to be recognised in the archaeological record.

Fruit bat demographic reconstructions from skeletal remains are rare in the literature and certainly not from archaeological studies. There is the potential to estimate age using a combination of tooth wear and tooth eruption criteria developed by Giannini et al (2006: 101). However, most of the Teouma fruit bat tooth rows were empty, the teeth usually recovered separately. The only available means to estimate bat age at Teouma was epiphyseal fusion data for long bones and vertebra. However, the order of long bone epiphyseal fusion has yet to be established based on reliable data. Despite these limitations, here an attempt to estimate this order of bat long bone fusion was made. This was conducted using logical reasoning based on typical mammal timetables of fusion adjusted for the unique flight adaptations on the bat skeleton. The most reliable aging methods for live bats appears to be epiphyseal fusion of long bones in the wing around the time sub-adult bats become volant after 6-8 weeks of age, although these findings have been based on external visual examination of wing phalange-metacarpal epiphyseal fusion and wing forearm length (Anthony 1988; Kunz and Anthony 1982). Bats are weaned soon after becoming volant at about which time they reach full adult skeletal maturity soon afterwards. Therefore it is reasoned here that wing bones are early fusing to allow flight as soon as possible. This is seen from osteogenesis occurring first in the clavicle, humerus, radius and ulna, with the lower limb femur, tibia, and

fibula elements forming last (Adams 1992). As such un-fused early fusing wing long bones are assumed here to be an indicator of juvenile individuals, while un-fused leg bones are likely to fuse soon after flight at the point of skeletal maturation and could represent sub-adult or juveniles equally. Adults are characterized by fused epiphyses.

### *5.4.2 Pig husbandry*

Predicting optimization and economic rationality in pig husbandry is problematic and it was established in Chapter 4 how pigs are managed for a variety of short-term and long-term goals for social, economic and ideological purposes. Reconstructing pig demographic patterns allows an understanding of animal husbandry management practices which could reflect a range of goals and strategies pursued over time at Teouma. Prehistoric pig husbandry methods have been interpreted from archaeological demographic studies of pig faunal remains. These have typically demonstrated that a narrow range of younger sub-adult to young adult pigs represented in an assemblage usually indicate pigs were being managed intensively for optimal meat production, while hunting feral pig populations could be expected to show a broader range of ages (Golson and Hughes 1980; Horton and Ward 1981; Rolett and Chiu 1994; Smith 2000; Walter 1998; West 2007). Hide (2003) argues that optimal management systems outlined in archaeological studies are more associated with modern commercial piggeries and understanding the traditional demographic structure of existing village domesticated pig populations in the Pacific might help develop more realistic models to explain archaeological demographic data for pigs. These studies so far have indicated a range of short and long term goals are practiced in the typical traditional island village resulting in significant variation in pig demography over short time frames. These pig exploitation goals are predicted here to establish clear demographic profiles.

It was predicted in Chapter 4 that if pigs were managed for dietary reasons then this would be done in a short term optimal fashion by minimizing costs with a low intensity management strategy. For optimal results pigs are killed in a narrow sub-adult and young adult age range between 5-24 months when pigs are growing at their fastest (see Rolett and Chiu 1994). Feeding pigs longer may increase their size by another 25% but the labour costs are prohibitive. Alternatively if feral pigs became abundant a more optimal pig exploitation strategy may be to hunt pigs in the terrestrial patch as these

would incur typically lower search and post encounter costs as opposed to prohibitive labour costs associated with increased pig production. However, increased feral populations may also increase domestic patch labour costs by damaging crops, which may require labour inputs to construct fences to keep them out. Feral pig hunting is likely to produce a demographic profile of mostly prime adults with few juveniles and mature adults (see Lyman 1987 for hunted prey demographic profiles).

It was also predicted in Chapter 4 using costly signalling theory that an alternative more long term pig management strategy would focus on the labour intensive raising of pigs to mature ages for ritualistic feasts as displays of social and economic wealth. Ethnographically these pigs are spared no expense and are often housed or tethered and completely hand feed for over four years (Hide 2003; McIntyre 1997). It is also possible that very young suckling pigs may have been killed for cultural purposes (which at Teouma may have been related to mortuary rituals), although there is no ethnographic record that could be indicative of such activity in the Asia-Pacific region.

In this study pig age is estimated using well established time-tables for tooth eruption (Bull and Payne 1982; Silver 1969), tooth wear (Grant 1982; Rolett and Chiu 1994) long bone epiphyseal fusion (Silver 1969; Schmid 1972), and bone size and porosity (Reitz and Wing 1999). Each method has its strengths and weaknesses and in many cases complement or overlap each other. Here I combine these disparate methods of ageing pig vertebrate remains quantified by MNI (Minimum Numbers of Individuals) into six ontological age classes expressed in months. These include infant (0-1 month), juvenile (1-5 months), sub-adult (5/8-10/14 months), young adult (10/14-18/24 months), prime adult (24-42 months), and mature adult (42 months+) by temporal unit. Pig age profile reconstruction was complex because of the different methods used and combining these three methods into an overall profile of pig mortality proved challenging. The potential for duplication of data from the same pig individuals using these different methods is avoided by calculating MNI using each method and taking the highest value for each age class.

Assumptions were unavoidable in applying these methods. For instance it was assumed that pig teeth and long bones consistently erupt and fuse at predictable intervals, and that the attrition rate for teeth is similar when comparing assemblages. However this is not likely to be the case as environment, climate, and diet are likely to influence these

attributes and result in small variation in tooth maturation (Rolett and Chiu 1994). Much of this will depend on how the pigs are being managed prehistorically but at least the methods used will be consistent and differences as a result of variability in pig maturation rates are likely to be small.

Other problems exist with relative representation of age classes using epiphyseal fusion data. Quantifying age classes using this kind of data results in differential representation as mature adults and juveniles are usually over-represented due to clearly demarked fusion periods while sub-adults and young adults tend to get under-represented by age ranges that overlap. Fusion data also do not distinguish in fine enough detail the difference between infants, juveniles, and sub-adults because, for example, a distal humerus which fuses at 12 months does not tell us anything about the three age classes that fall under this age.

This problem can be restricted using tooth eruption and tooth wear data which are the best for distinguishing between sub-adults, young adults, and prime adults between 5-26 months because of their more specific timetables of eruption and wear around this age range, which can even be applied to loose individual molars (Rolett and Chiu 1994). But these data become less useful once pigs reach full skeletal maturity after 26 months. This method also relies on a significant quantity of cranial and mandible elements being represented in proportions similar to post cranial elements.

Identifying pig bones to more specific immature pig age classes based on size and porosity (Figure 5-2) has the advantage of a more specific age for pigs under one year that is not currently available for epiphyseal fusion data. It also has the advantage of being independent of the need for bones with complete zones of epiphyseal fusion which are not often found in archaeological assemblages. But this method has the potential to over-represent immature age classes relative to adults despite the fragility of infant and juvenile bones being less likely to survive in similar proportions to more dense adult skeletal material.

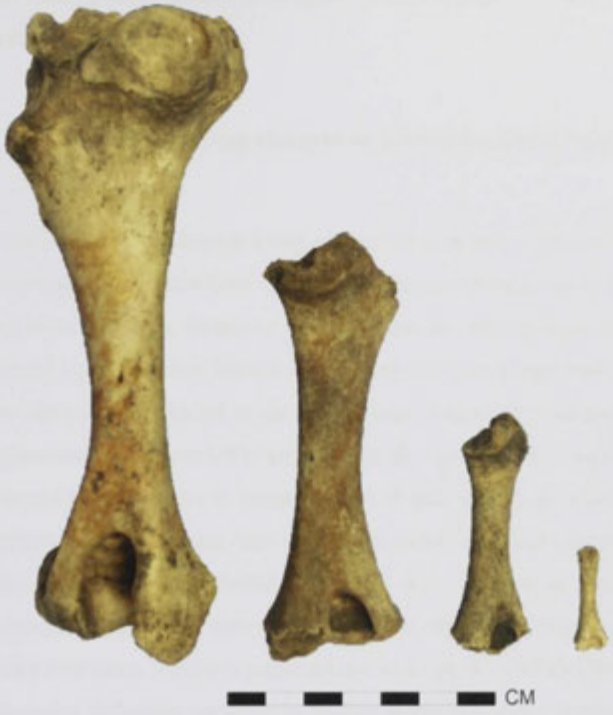


**Figure 5-2: Different pig humeri ages based on size, porosity and epiphyseal fusion. Left to right, mature adult, sub-adult, juvenile, infant.**

Finally distinguishing the sex of pigs can also provide useful information on pig demography and husbandry practices. Generally sex data is not usually provided for prehistoric pig management reconstructions in the Pacific. In one rare study in the Banks Islands in Northern Vanuatu high proportions of males have been associated with a focus on trade and optimal dietary contributions to the local islet economy of Pakea (Horton and Ward 1981). Alternatively higher proportions of female pigs may be identified with mixed pig management systems. Today in some parts of northern Vanuatu female pigs are not allowed to be eaten by men in ritual contexts, but merely used to breed with feral boars to produce males that are castrated to produce tusker pigs for demonstrations of wealth and power (e.g. Deacon 1934). It is predicted here that an uneven focus on males or females could indicate a specific pig husbandry system may have been practiced while a more even distribution of males and females could indicate a variety of pig husbandry practices. Pig sex was determined by canine morphology

with males clearly identified by open root and females by closed root canines (Schmid1972).

## 5.5 Measuring changes in intensification of prey utilization

It was predicted in Chapter 4 that a potential response to resource depression could involve spending more time within a resource patch processing individual high ranked prey more intensely. Resource intensification has already been implied using skeletal element representation. Here it is predicted that resource processing intensification is also likely to be reflected in the archaeological record by increased rates of butchery and fragmentation. Typical OFM studies (see Broughton 1999; Nagaoka 2000) focus on demonstrating changes in intensification of individual prey utilization by examining changes in fragmentation rates assumed to relate to carcass processing by humans using a simple measure (NISP/MNE ratio). This study expands on this, incorporating not just fragmentation rates but also changes in rates of observed butchery fractures and cut marks over time. Butchery patterns have been used to infer different intensity of carcass processing reflecting variation in carcass utilization spatio-temporally at the intra-site level or between sites (e.g. Bunn and Kroll 1986; Lyman 1992, 2005; Nagaoka 2000; Rapson 1990). It is rationalized here that butchery marks may intensify on high ranked elements as more meat is removed, but also may appear more frequently on lower ranked elements over time as these become more intensively utilized. Below, the datasets including temporal changes in NISP/MNE ratios, changes in cut mark frequencies, and changes in human associated fracture patterns are elaborated.

### *5.5.1 NISP/MNE ratios*

A common measure used to demonstrate fragmentation is to divide NISP by MNE to create a fragmentation ratio (Grayson 1984). High ratios indicate high fragmentation rates; conversely low ratios indicate low fragmentation rates. Its strength is its simplicity, but it does assume that fragmentation rates are a result of human processing, despite the possibility of differential post depositional fragmentation. If higher intensities of butchery and consumption occur over time in response to resource depression then this should be reflected in higher fragmentation rates over time.

### *5.5.2 Changes in cut mark frequencies*

The number of cut marks was recorded on each skeletal element including the approximate location based on portion and segment codes i.e. proximal, distal, shaft for long bones and diagnostic zones on cranial, mandibular, vertebra, and pelves. Generally these were easy to detect using low levels of magnification and distinctive V shaped cuts were observed by blind experimental tests (Blumenschine 1996). Changes in cut mark frequencies were measured in two ways both using MNE. Firstly the proportion of bones with cut marks and secondly the average number of cut marks per bone with cut marks.

However, this study is based on the assumption that butchery marks accurately reflect intensity of butchery practices across different taxa and different skeletal elements within individual taxa. More recent experimental studies have suggested that a variety of other factors may account for cut mark variation within and between archaeological assemblages (Egeland 2003; Lyman 2005). Clearly different skeletal elements have varying potential to receive cut marks. Ethnoarchaeological experiments were carried out by Egeland (2003) which demonstrated no link between the intensity of processing activities and the resultant frequency of butchery cut marks. This is especially true for the frequencies of cut mark striae on skeletal elements. This variation it was reasoned was probably more a result of inherent skeletal element morphology, and/or variation in the associated insulating meat mass for bone surfaces. In other words differences in bone form and surface protection could influence cut mark frequencies. High ranked skeletal elements with greater meat masses could actually have lower frequencies of observed cut marks. Therefore caution must be practiced when incorporating such a study within OFM. While not perfect, the proportion of skeletal elements with cut marks has proved a more useful measure of butchery intensity than the frequencies of cut marks (Egeland 2003; Lyman 2005).

### *5.5.3 Changes in human related bone surface modifications*

Humans have been associated with specific bone surface modifications, reflected in fracture shape orientation and surface morphology (Morales 1988; Shipman et al 1981; Sadek-Kooros 1975). These studies have been useful for distinguishing early hominid scavenging from hunting as well as human accumulated bone assemblages from natural assemblages. Using these experimental criteria set out by Sadek-Kooros (1975) and elaborated on by others, fracture patterns here are characterized by orientation, shape and fracture surfaces with oblique and transverse regular fractures most commonly associated with butchery practices. This study attempts to determine if the proportions of these types of human associated bone fractures increased over time in response to declines in foraging efficiency.

### *5.5.4 Non dietary related utilization of fauna*

Animals are often traditionally used for functional and ceremonial purposes within a society, including the manufacture of tools and ornaments. Such artefacts were reported when observed. The presence of unique species not usually associated with human consumption may also be an indication of their use for social reasons, although alternatively they could represent opportunistic hunting behaviour.

## 5.6 Statistical analysis

Quantified studies require statistical analysis to test if the results indicate a significant temporal trend in dietary contributions. Typically Pearson's R (Broughton 1994; McAlister 2002) or Spearman's rank $r_s$ (Broughton 2002; Nagaoka 2000) is used to test the significance of temporal trends in subsistence behaviour and the relationship to sample size, which can have a significant effect. Because significant errors can be amassed using Spearman's $r_s$ to test the relationship of relative abundance of taxa to sample size (Cannon 2001), these tests are not conducted in this study.

Instead, Cochran's test of linear trends was employed in this thesis using the Chi-square and Cochran's calculator online (Cannon n.d.). It is considered by Cannon (2001) to be the most parsimonious statistical method to test OFM data because it results in fewer errors by taking sample size into account. This test is explained elsewhere (Cannon 2001, n.d.; Zar 1996) but summarized briefly here, it is a Chi-square analysis that can determine a significant direction of subsistence behaviour by tracking changes in the proportions of two variables (e.g. two species, NISP) taking into account the natural ordering of a temporal stratigraphic sequence. The test is conducted in two parts; $X^2_{trend}$ and $X^2_{departure}$. The former tests the significance of a directional linear trend, reflecting the variability in proportions of variables across a time sequence. The $X^2_{departure}$ is also able to test if there is any significant noise or departure from a linear trend. Both tests provide a significance p value and are incorporated in this thesis to test both linear and non-linear changes in the relative abundance of two variables over time. Spearman's $r_s$ (calculated using PAST) is used here to also determine significant trends in two ordinal data-sets where the natural order is not relevant.

Because the spatio-temporal units (described in Chapter 3) between the cemetery and adjacent Lapita midden area overlap (Units D, C3-C1) within the Lapita period, a number of these units need to be tested in a manner that takes this into account. Statistical tests were conducted separately on two distinct spatio-temporal groups, the Lapita midden (Units C3-C1) and the cemetery/post cemetery (Cemetery Unit D, post-cemetery Lapita midden B2, post-cemetery Erueti midden B1). Data with small sample sizes was deemed unfit for statistical analysis and merely interpreted through qualification (Unit A).

## 5.7 Summary

Five multi-proxy datasets and their procedures (including statistical analysis) used to test HBE predictions (see Chapter 4) were discussed at length. These methods were chosen to measure changes in prey abundance and diversity, individual prey utilization, foraging efficiency and resource depression. Prey diversity measures of Diet Breadth and evenness are used to test for changes in prey structures, general foraging strategies and inferred foraging efficiency. Relative abundance using simple ordinal rankings test for general subsistence trends and abundance indices (AI) measure more specifically

changes in foraging efficiency through changes in the ratio of high ranked taxa relative to low ranked taxa. Demographic estimates of prey populations were incorporated into the research design to test directly the relationship between Lapita foraging behaviour and resource depression. It was also used to provide details on pig husbandry practices from which to interpret pig utilization and distinguish optimal pig management from social-political aspects of Lapita culture. Skeletal element representation outlined above is employed to test predicted responses to resource depression and declining foraging efficiency by examining changes in intensity of individual prey utilization and decisions to reduce distance related transport costs. Predicted changes in prey carcass processing intensity in response to resource depression are further measured through changes in fragmentation, cut marks and butchery fracture rates.

# 6 Measuring Temporal Changes in Prey Diversity and Relative Abundance

This chapter is focused on testing the predictions made by the Prey Choice Model and Patch Choice Model outlined in chapter 4. These predictions are focused on temporal changes in prey choice during the Lapita to Post-Lapita transition. Changes in the foraging efficiency during this period using reptile, mammal, and bird taxonomic data are measured within the general terrestrial, coastal and domestic resource patches. More specifically it was predicted, using the Prey Choice and Patch Choice models in Chapter 4 that larger high ranked reptiles would always be targeted when encountered. The adverse effect on subsequent encounter rates should result in resource depression, resource intensification, broadening diet and declines in foraging efficiency. This chapter also addresses the Marginal Value Theorem (MVT) by demonstrating how long foraging occurred within each patch by measuring changes in foraging efficiency between these three resource patches. The MVT and Central Place Foraging Model (Charnov 1976; Orians and Pearson 1979) also predicted that large bodied reptiles would be targeted in increasingly distant resource patches as resource patches closer to Teouma declined in foraging efficiency. Here, prey diversity (diet breadth and evenness) and relative abundance (rank order, proportions of relative taxonomic abundance, Abundance Indexes) datasets are used to measure changes in foraging efficiency, although the link between foraging behaviour and resource depression is indirect and inferred only.

The data associated with two distinct overlapping spatio-temporal units, the Lapita midden (Units C1, C2, C3) and the cemetery/post cemetery deposits (Temporal units D, B2, B1, A) are displayed as two separate but related stratigraphic datasets in scatter plot graph form. The temporal units are displayed on the x-axis with the oldest units

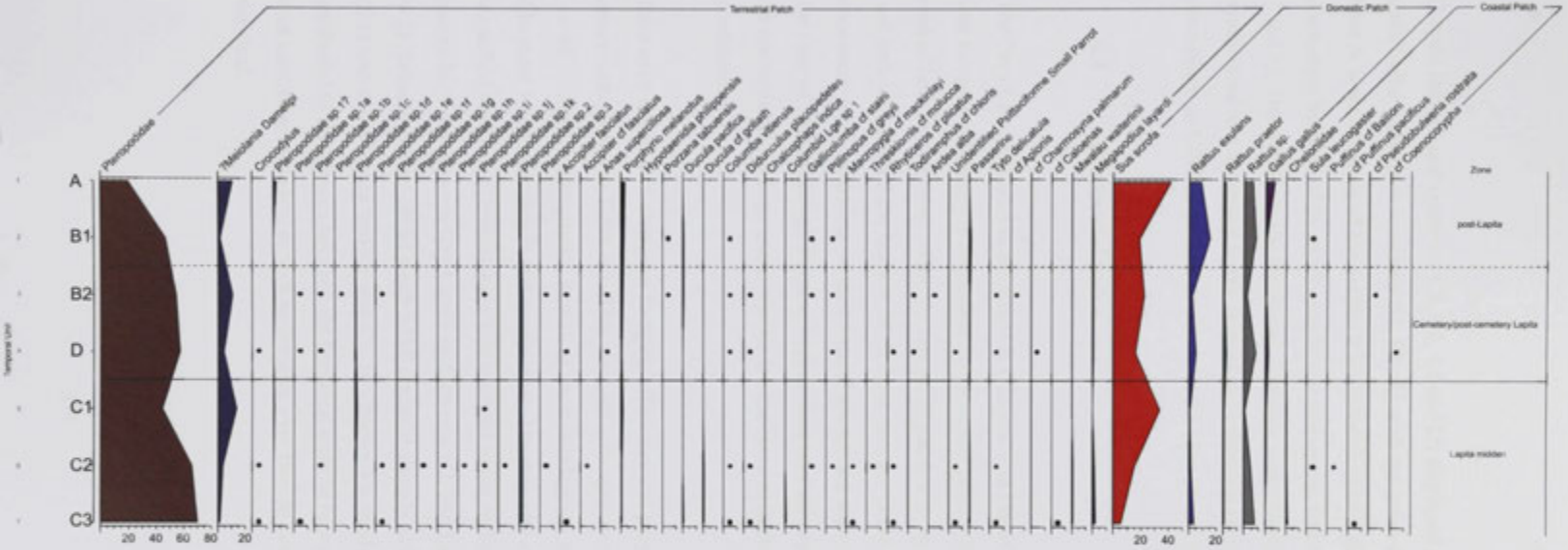


**Figure 6-1: Teouma reptile, mammal and avian taxon relative abundance, %NISP (rare taxa shown as present with a dot), by temporal unit**

(Lapita midden and cemetery C3, C2, C1 and D) displayed from left to the youngest units to the right (post cemetery B2, B1, A) with the index data on the y-axis. While Unit A is included on all the graphs it is excluded from statistical analysis and discussion because of its small sample size and coarse recovery methods (see Chapters 3 and 5). The data from the terrestrial, domestic and coastal resource patches are synthesized in a summary figure (Figure 6-1) showing all taxa by temporal unit as a percentage of NISP or present or absent in the case of rare taxa.

## 6.1 Terrestrial patch

The Prey Choice Model as discussed in Chapter 4 and briefly recapped here predicts that foraging efficiency is dependent on encounter rates of high ranked taxa. These are ranked here by prey size within the terrestrial patch with large game reptiles; crocodile and tortoise's ranked the highest. Both these taxa are likely to have initially different encounter rates depending on their natural abundance within their respective habitats at the time of human arrival. Because high ranked taxa are expected to be always captured on encounter these large game reptiles are expected to decline as a result of human predation.

Data used to measure changing foraging efficiency and prey diversity for the terrestrial patch is presented in Table 6-1. This includes only specimens identified to taxa leaving out all unidentified fragments as well as most overlapping tentative identifications (see Chapters 3 and 5 for details and exceptions). The majority of the terrestrial patch identified vertebrate remains were concentrated in the earlier temporal units and most particularly in post-cemetery Lapita midden unit B2, and Lapita midden unit C2 (Figure 6-2). Subsequent terrestrial patch NISP declined sharply in the Post Lapita temporal unit (B1) and in the Lapita midden unit C1. In Chapter 3 a similar pattern for total NISP was attributed to differences between the temporal units in recovery methods, excavation area size, time averages, as well as declines over time in faunal abundances observed in the field.

**Table 6-1: Terrestrial patch identified taxa NISP and NTAXA by analytic temporal unit**

| Taxa | C3 | C2 | C1 | D | B2 | B1 | A | Total |
|---|---|---|---|---|---|---|---|---|
| **Reptile** | | | | | | | | |
| *?Meiolania Damelipi* | 27 | 184 | 75 | 161 | 872 | 17 | 9 | 1345 |
| *Crocodylus* | 10 | 6 | 0 | 10 | 0 | 0 | 0 | 26 |
| **Mammal** | | | | | | | | |
| *Pteropodidae* | 1886 | 3580 | 256 | 2292 | 4450 | 603 | 17 | 13084 |
| *Pteropodidae sp.1?* | 0 | 0 | 6 | 18 | 88 | 6 | 2 | 161 |
| *Pteropodidae sp.1a* | 1 | 0 | 0 | 1 | 17 | 0 | 0 | 19 |
| *Pteropodidae sp.1b* | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 3 |
| *Pteropodidae sp.1c* | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| *Pteropodidae sp.1d* | 11 | 17 | 6 | 25 | 19 | 1 | 0 | 79 |
| *Pteropodidae sp.1e* | 1 | 2 | 0 | 0 | 2 | 0 | 0 | 5 |
| *Pteropodidae sp.1f* | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| *Pteropodidae sp.1g* | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 2 |
| *Pteropodidae sp.1h* | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| *Pteropodidae sp.1i* | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| *Pteropodidae sp.1j* | 0 | 2 | 1 | 0 | 1 | 0 | 0 | 4 |
| *Pteropodidae sp.1k* | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| *Pteropodidae sp.2* | 69 | 147 | 9 | 87 | 190 | 15 | 1 | 518 |
| *Pteropodidae sp.3* | 0 | 3 | 0 | 0 | 11 | 0 | 0 | 14 |
| **Bird** | | | | | | | | |
| *Accipiter fasciatus* | 1 | 0 | 0 | 3 | 14 | 0 | 0 | 18 |
| *Accipiter cf fasciatus* | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| *Anas superciliosa* | 0 | 0 | 0 | 1 | 11 | 0 | 0 | 12 |
| *Porphyrio melanotus* | 5 | 15 | 6 | 10 | 83 | 21 | 2 | 142 |
| *Hypotaenidia philippensis* | 2 | 9 | 2 | 3 | 13 | 11 | 0 | 40 |
| *Porzana tabuensis* | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 4 |
| *Ducula pacifica* | 12 | 20 | 0 | 13 | 34 | 10 | 0 | 89 |
| *Ducula cf goliath* | 12 | 15 | 0 | 5 | 3 | 1 | 0 | 36 |
| *Columba vitiensis* | 4 | 6 | 0 | 9 | 14 | 5 | 0 | 38 |
| *Didunculus placopedetes* | 8 | 29 | 0 | 1 | 3 | 0 | 0 | 41 |
| *Chalcophaps indica* | 10 | 11 | 0 | 4 | 7 | 3 | 0 | 35 |
| Columbid Large sp 1 | 21 | 0 | 0 | 1 | 0 | 0 | 0 | 22 |
| *Gallicolumba cf stairii* | 0 | 5 | 0 | 0 | 1 | 1 | 0 | 7 |
| *Ptilinopus cf greyii* | 0 | 1 | 0 | 1 | 4 | 4 | 0 | 10 |
| *Macropygia cf mackinlayi* | 4 | 5 | 0 | 0 | 0 | 0 | 0 | 9 |
| *Threskiornis cf molucca* | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| *Rhyticeros cf plicatus* | 2 | 3 | 0 | 1 | 0 | 0 | 0 | 6 |
| *Todiramphus cf chloris* | 0 | 0 | 0 | 3 | 2 | 0 | 0 | 5 |
| *Ardea alba* | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| Unidentified Psittaciforme Small Parrot | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 3 |
| *Passerine* | 14 | 18 | 0 | 15 | 28 | 12 | 0 | 87 |
| *Tyto delicatula* | 1 | 6 | 0 | 4 | 3 | 0 | 0 | 14 |
| *cf Aplonis* | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 3 |
| *cf Charmosyna palmarum* | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 3 |
| *cf Caloenas* | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| *Mwalau walterlinii* | 22 | 24 | 0 | 0 | 0 | 0 | 0 | 46 |
| *Megapodius layardi* | 45 | 52 | 0 | 13 | 25 | 3 | 0 | 138 |
| Total | 2171 | 4170 | 361 | 2686 | 5903 | 715 | 31 | 16078 |
| NTAXA | 23 | 31 | 6 | 25 | 27 | 14 | 4 | 39 |

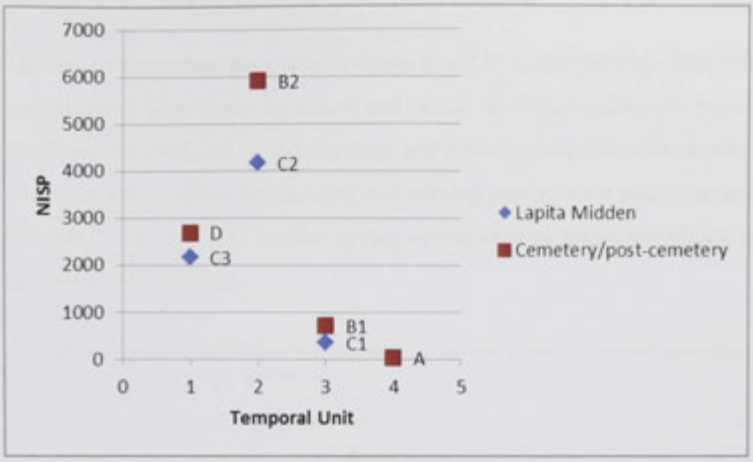


**Figure 6-2: Terrestrial patch identified NISP by temporal unit.**

### *6.1.1 Diet Breadth*

The Diet Breadth model predicted that NTAXA would expand as a result of resource depression of high ranked resources indicating a decline in foraging efficiency. However, this is problematic given the disparity in sample sizes visible in Figure 6-3 where a linear trend between sample size and NTAXA is apparent for the Lapita midden (C3-C1) but not so strong for the cemetery/post-cemetery units (D, B2-B1, A). In Figure 6-4, taking sample size into account, NISP/NTAXA indicates that there were some real changes in animal exploitation activities occurring from the Lapita cemetery (Unit D) with diet breadth increasing sharply during the Lapita midden unit C2 and by the post-cemetery Lapita midden unit B2.

While the problems in disparate sample sizes are problematic this relationship is likely also to be influenced by a combination of declining faunal abundance and diversity. Resource intensification and diet breadth appears to peak in units C2 and B2 as foraging efficiency declined. By the end of the Lapita midden (Unit C1) and the post-cemetery Erueti midden (B1) NISP and NTAXA declined rapidly indicating a faunal collapse as extinctions of crocodiles, bats, and birds and declining prey abundances occurred. Of course all this assumes that the rate of deposition throughout the temporal units remained constant representing actual changes in subsistence behaviour and waste disposal proximal to the settlement.

The rate of deposition per quantified taxa could be determined by calculating NTAXA and NISP per litre of soil excavated and sieved. Such data collection, however, while ideal was not practiced during the large and already complicated excavations at Teouma where the nature of the stratigraphy and varying preservation across the site (see Chapter 3) does not lend itself to giving information on faunal abundance per excavation volume unit.

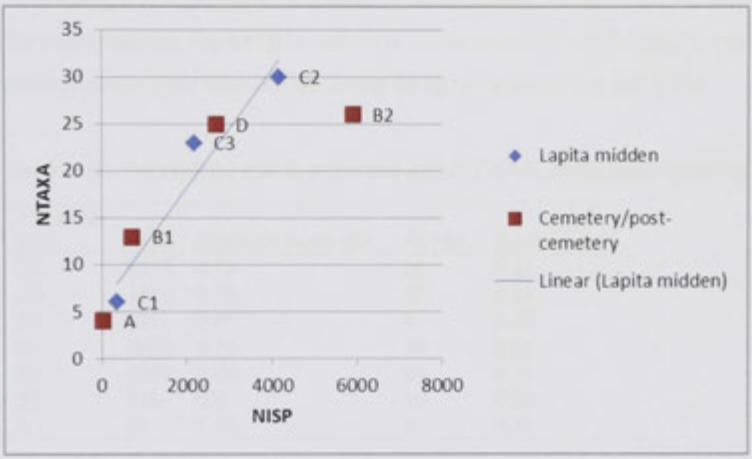


**Figure 6-3: NTAXA relationship to sample size (NISP) for the terrestrial patch**

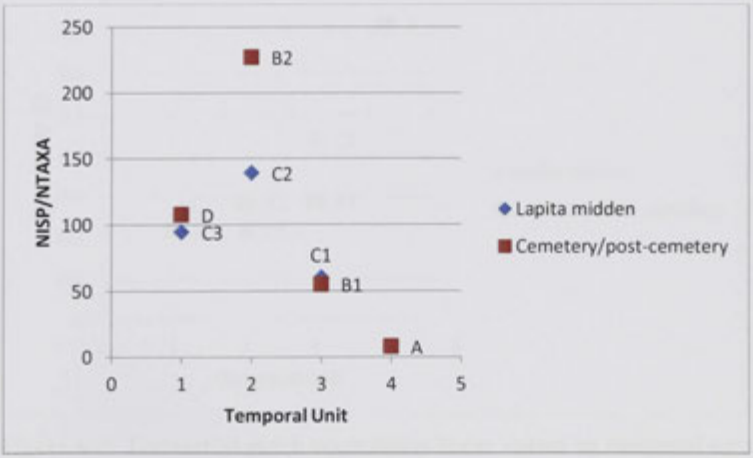


**Figure 6-4: Terrestrial Patch NISP/NTAXA by temporal unit**

### *6.1.2 Equitability (Evenness)*

If initially the Lapita colonists gained high foraging efficiency within the terrestrial patch by focusing on a few high ranked taxa such as crocodiles and tortoises this could result in an uneven exploitation of a small range of taxa. Equitability (evenness) values are presented in Table 6-2 and plotted in Figure 6-5 and show that specialization on fewer taxa occurred during the early Lapita period units D, C3-C2 but increased in equitability and thus more even focus on more resources occurred during unit C1 and the post-cemetery Lapita (B2) and early Erueti units (B1) indicating increasing generalization over time and declining foraging efficiency as predicted.

**Table 6-2: Terrestrial patch evenness and NTAXA index data by temporal unit.**

| Temporal Unit | NISP | Shannon Index (H) | NTAXA | Equitability E |
|---|---|---|---|---|
| C3 | 2171 | 0.72 | 24 | 0.23 |
| C2 | 4170 | 0.73 | 32 | 0.21 |
| C1 | 361 | 0.91 | 8 | 0.44 |
| D | 2686 | 0.72 | 26 | 0.22 |
| B2 | 5903 | 0.95 | 29 | 0.28 |
| B1 | 715 | 0.8 | 16 | 0.29 |
| A | 31 | 1.15 | 5 | 0.72 |

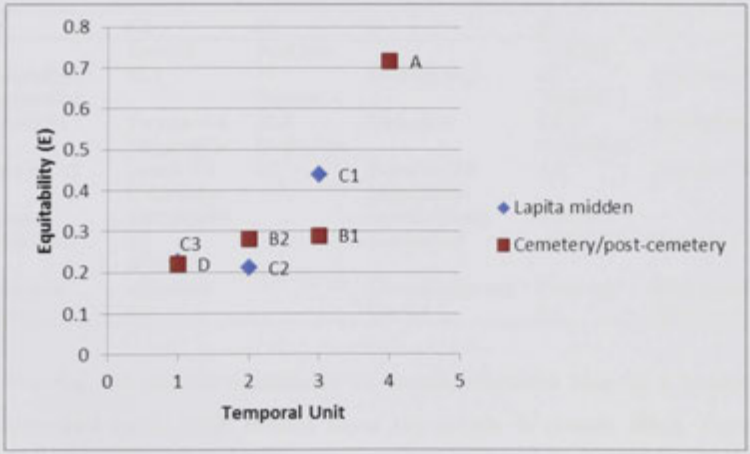


**Figure 6-5: Terrestrial patch equitability index values by temporal unit**

### *6.1.3 Relative abundance*

In Table 6-3 the five top ranked taxa by temporal unit indicate that taxonomic abundance at Teouma changed little over time. Fruit bat is consistently the top ranked taxa at Teouma by temporal unit and tortoise is ranked second in all Lapita temporal units apart from the earliest Lapita unit C3. In most temporal units these two taxa make up over 90% of the identified terrestrial patch NISP. By the Erueti period (B1) tortoise rank drops reflecting its rapid decline. The high proportion of tortoise bones in the post deposition Unit A top soil (Layer 1) is a result of recovery methods, small sample sizes and minor disturbances. Another clear pattern demonstrated by the rank order abundance table is that there is change between the cemetery and the post-cemetery phase temporal units for taxa ranked 3-5. Forest birds are higher ranked during the early Lapita phase (D, C3-C2) with wetland birds such as swamp hen and banded rails consistently gaining in rank from later Lapita units C1, B2 and Early-Erueti (post-cemetery) unit B1, while there is a corresponding decline in forest bird taxa rankings. This appears to represent a shift in bird exploitation from forest birds to wetland birds over time at Teouma.

**Table 6-3: Terrestrial patch relative abundance top five ranked taxa with percentages of total identified terrestrial taxon NISP.**

| Rank | C3 | C2 | C1 | D | B2 | B1 | A |
|---|---|---|---|---|---|---|---|
| 1 | Fruit bat 90.7 | Fruit bat 90.1 | Fruit bat 77 | Fruit bat 90.3 | Fruit bat 81 | Fruit bat 87.4 | Fruit bat 64.5 |
| 2 | Megapodius layardi 2.1 | Tortoise 4.4 | Tortoise 20.8 | Tortoise 6 | Tortoise 14.8 | Swamphen 2.9 | Tortoise 29 |
| 3 | Tortoise 1.2 | Megapodius layardi 1.3 | Swamphen 1.7 | Passerine 0.6 | Swamphen 1.4 | Tortoise 2.4 | Swamphen 6.5 |
| 4 | Mwalau walterlinii 1 | Didunculus placopedetes 0.7 | | Megapodius layardi/Ducula pacifica 0.5 | Ducula pacific 0.6 | Passerine 1.7 | |
| 5 | Columbid large sp. 1 | Mwalau walterlinii 0.6 | | Crocodile/Swamphen 0.4 | Passerine 0.5 | Bluff-banded rail 1.5 | |

Viewing the relative abundance of certain terrestrial taxa as a proportion of total terrestrial patch NISP reveals some key trends in greater detail. Fruit bat relative abundance (Figure 6-6) reveals some significant changes over time. During the Lapita midden period it significantly declined from C2 to C1 (Lapita midden $X^2_{trend} = 23.9$, $P = < 0.001$; $X^2_{departure} = 42.13$, $P<0.001$). The cemetery to post-cemetery sequence indicates some significant fluctuation as fruit bat proportions declined from the cemetery (D) to

the post-cemetery Lapita (B2) period followed by an increase by the Erueti phase (B1) ($X^2_{trend}$ = 48.31, P <0.001; $X^2_{departure}$ = 76, P = <0.001). This contrasts with changes in tortoise relative abundance over time (Figure 6-7) which were significantly linear and non-linear, reflecting fluctuations in tortoise abundance. During the Lapita midden units C3 to C1 (Lapita midden $X^2_{trend}$ = 187.99, P < 0.001; $X^2_{departure}$ = 101.44, P<0.001) tortoise relative abundance significantly increased. During the cemetery (D) to post-cemetery units (B2-B1) an increasing linear trend during the Lapita period unit D to B2 was then followed by a decline by the early Erueti period (B1) (cemetery/post-cemetery $X^2_{trend}$ = 20.73, P < 001) with a significant non-linear trend (cemetery/post-cemetery $X^2_{departure}$ = 182.77, P =< 0.001). Other terrestrial taxa, present in small quantities, significantly declined and disappeared quickly by the end of the Lapita cemetery (D) and midden (C3-C1) period. These include crocodile (Figure 6-8: Lapita midden $X^2_{trend}$ = 6.62, P=0.01; cemetery/post-cemetery $X^2_{trend}$ = 19.39, P<0.001) and endemic extinct bird species Lini's giant megapode (Figure 6-9: Lapita midden $X^2_{trend}$ = 6.57, P=0.01), Tongan Tooth-billed pigeon (Figure 6-10: Lapita midden $X^2_{departure}$ = 4.55, P=0.03) and *Columbid large nsp 1* (Figure 6-11: Lapita midden $X^2_{trend}$ = 36.78, P<0.001).

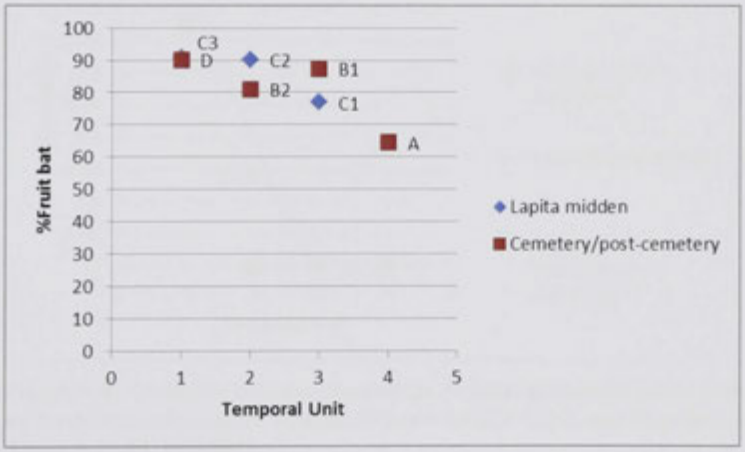


**Figure 6-6: Fruit bat relative abundance %Total terrestrial patch identified NISP by temporal unit (Lapita midden $X^2_{trend}$ = 23.9, P = < 0.001; $X^2_{departure}$ = 42.13, P<0.001; $X^2_{trend}$ = 48.31, P <0.001; $X^2_{departure}$ = 76, P = <0.001).**

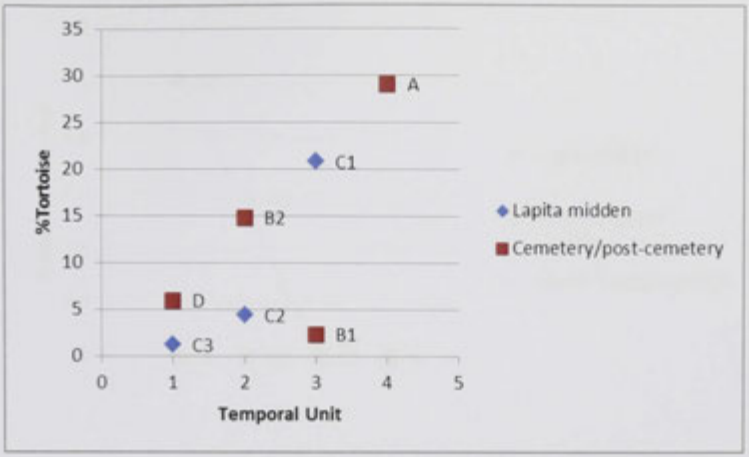


**Figure 6-7: Tortoise relative abundance %Total terrestrial patch identified NISP by temporal unit (Lapita midden $X^2_{trend}$ = 187.99, P < 0.001; $X^2_{departure}$ = 101.44, P<0.001; cemetery/post-cemetery $X^2_{trend}$ = 20.73, P < 001; $X^2_{departure}$ = 182.77, P =< 0.001).**

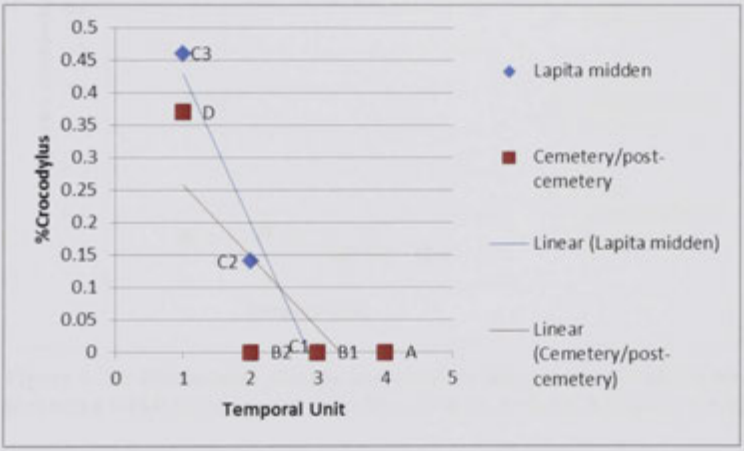


**Figure 6-8: Crocodile relative abundance %Total terrestrial patch identified NISP by temporal unit (Lapita midden $X^2_{trend}$ = 6.62, P=0.01; cemetery/post-cemetery $X^2_{trend}$ = 19.39, P<0.001).**

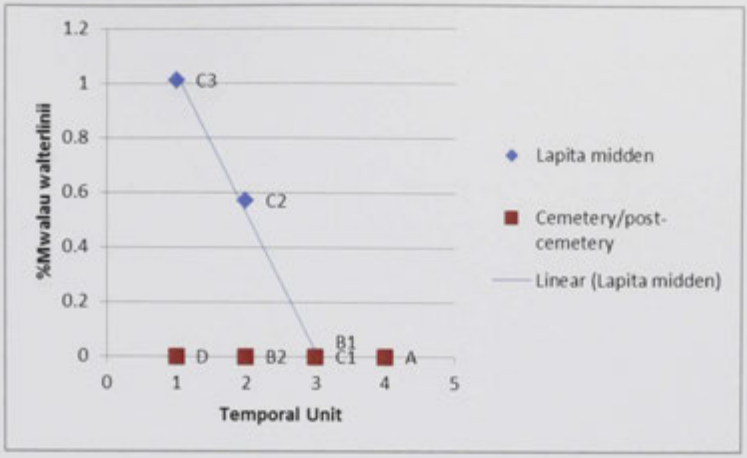


**Figure 6-9: *Mwalau walterlinii* relative abundance %Total terrestrial patch identified NISP by temporal unit (Lapita midden: $X^2_{trend}$ = 6.57, P=0.01).**

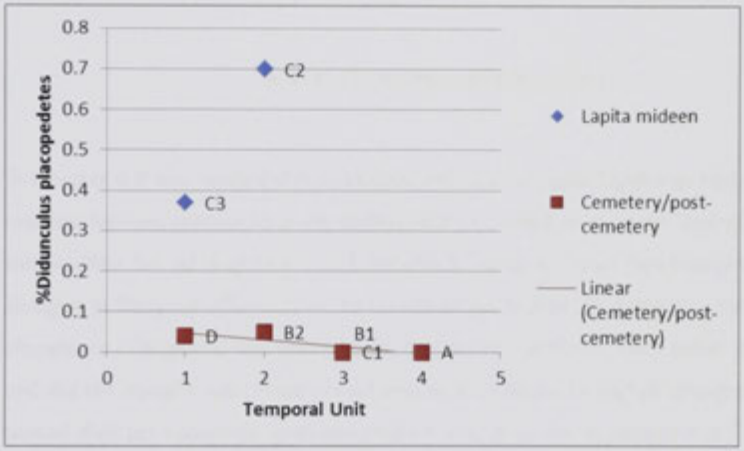


**Figure 6-10: *Didunculus placopedetes* relative abundance %Total terrestrial patch identified NISP by temporal unit ($X^2_{trend}$= 0.36, P=0.55; $X^2_{departure}$ = 4.55, P=0.03).**

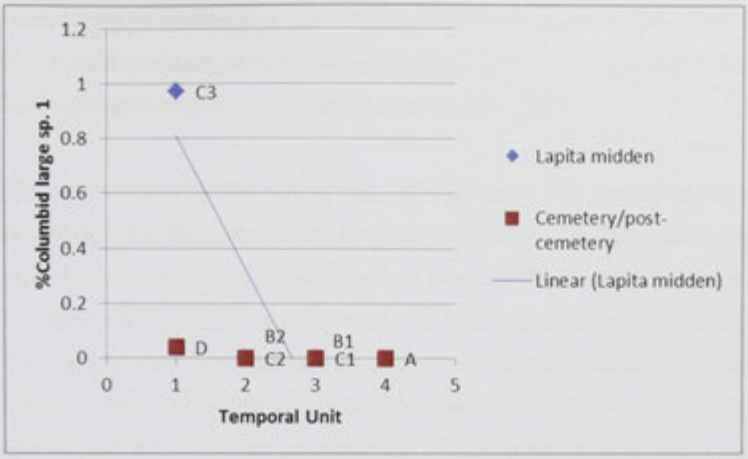


**Figure 6-11: Columbid large nsp 1 relative abundance %Total terrestrial patch identified NISP by temporal unit (Lapita midden $X^2_{trend} = 36.78$, $P<0.001$).**

### *6.1.4 Abundance Indexes (AI)*

In Chapter 4 it was predicted that foraging efficiency would decline as high ranked reptiles declined relative to lower ranked taxa as a result of resource depression. The tortoise/fruit bat AI (Figure 6-12) (Σ tortoise/Σ(Tortoise + fruit bat) was used to measure changes in foraging efficiency in the terrestrial patch through changes in the relative abundance of high and low ranked taxa. The results, however, were rather surprising and did not initially meet these predictions with consistently higher abundances of low ranked fruit bat vertebrate specimen relative to tortoise being exploited at Teouma throughout the entire sequence. This pattern was also observed in the rank order abundance in Table 6-3 above. The tortoise/fruit bat AI fluctuated over time indicating changes in foraging efficiency over very short time periods by archaeological standards. More specifically, against predictions of declines in high ranked tortoises over time, foraging efficiency of high ranked tortoise relative to low ranked fruit bat significantly increased in both linear and non-linear fashion during the early Lapita midden (C3-C1) temporal units (Lapita midden: $X^2_{trend} = 180.61$, $P < 0.001$; $X^2_{departure} = 93.22$, $P<0.001$). During the cemetery (D) to post-cemetery (B2-B1) periods foraging efficiency appears to fluctuate as tortoise abundance significantly increased relative to fruit bat from unit D to B2 as the cemetery transitioned to the post-cemetery Lapita period but then dramatically declined during the later Erueti unit B1 with significant departures

(cemetery/post-cemetery: $X^2_{trend} = 25.18$, $P<0.001$; $X^2_{departure} = 174.7$, $P<0.001$). These unexpected increases, before eventual decline, over time indicate that tortoise and fruit bat exploitation was more complex than previously predicted.

The most obvious answer may be that ranking taxa by size, appropriate in other studies (Griffiths 1975; Broughton 1999; Nagaoka 2000; Morin 2011), could be inappropriate when comparing tortoises versus fruit bats based on differences in net return rates. Fruit bats have a much smaller size, between 120-1000 grams (based on estimates of modern fruit bat species in Vanuatu see Flannery 1995b), than do tortoises. The giant Vanuatu tortoise is an extinct species so estimates of size can only be based on extant giant tortoise species, which can range between 30-250 kg (Bonin et al 2006). It could potentially take a few hundred bats to equal one tortoise in terms of meat content, and it is likely that despite the higher abundance of fruit bat bones tortoises still probably provided the greater share of protein and fat. But prey size rankings do not take into account costs associated with searching, travel, and capture and processing of different taxa (Ugan 2005); they merely assume economies of scale with regards to larger meat packages.

In particular, certain costs associated with distance from site (Metcalf and Barlow 1992) or processing large quantities of individuals during mass harvesting (Madsen and Schmidt 1998; Ugan 2005) are known to be quite prohibitive. But for fruit bat exploitation these would have been quite minimal, allowing the mass harvest of a large number of fruit bats at much lower costs than incurred during tortoise hunting and processing. Some fruit bat species in the Pacific have been known to roost in trees in loud, easy-to -locate colonies numbering in their thousands (Flannery 1995b). One can imagine at the time of Lapita arrival that fruit bats, lacking defences in the absence of predators, would have been easy to locate and capture in great numbers in predictable locations close to the Teouma site. They are also cooked with minimal preparation by removing the fur and wings and then usually roasted over a fire (Speiser 1991) thus reducing prohibitive processing costs and making mass harvesting highly effective in gaining substantial net returns in energy. Tortoises on the other hand may have potentially been much more difficult to locate in the forest at a variety of distances from the site especially as encounter rates declined and were likely to incur higher search, transport and processing costs over time.

However, whether this was enough to rank fruit bats higher than tortoises is a difficult proposition. Comparing return rates between these taxa is fraught with difficulties because of a lack of understanding of the exact details of relative costs and benefits to determine more precise relative net returns; variables which for these two taxa remain unknown. One thing is clear, fruit bats were far more abundant than tortoises in the terrestrial ecology surrounding Teouma right from the beginning of the archaeological sequence and this is reflected in greater proportions being exploited.

The tortoise/fruit bat AI could also actually be measuring changes in subsistence strategies between different more specific resource "patches" rather than efficiency within a single general terrestrial patch, as distance related costs for central place foragers at Teouma may have had a greater influence on optimal decisions. Although the Vanuatu giant tortoise ecology is uncertain, based on knowledge of other giant tortoises in island environments on Aldabra Atoll and in the Galapagos Islands, herds of tortoises are likely to have been found clustered in a wide variety of habitat localities (within forested habitats from the coast to the interior) feeding on vegetation they had coevolved with. It is likely, therefore, that tortoises were initially widespread in dense concentrations on Efate and other islands. Being large meat packages and easy to catch, they are likely to have been taken at a range of distances from Teouma. Fruit bat palaeoecolgy is also uncertain and may have roosted and foraged in a wider range of habitats then what is known today. Most extant fruit bat species today inhabit large trees with few leaves in small to large colonies within specific predictable locations that they continuously occupy, even in the face of continuous human predation (Flannery 1995b). However, bats being small game and providing only small meat packages are likely to have been captured close to the site and as such are good indicators of settlement intensification (Munro et al 2004).

Increasing proportions of tortoise bones over time could indicate a response to proximal tortoise depletion by increasing mobility and acquisition of tortoises in increasingly more distant forest environs; decreases in the tortoise/fruit bat AI would indicate greater resource intensification and declines in foraging efficiency. With this interpretation of the relative costs and benefits of tortoises and fruit bats, when the spatial distribution of proximal 'fruit bat' and distant 'tortoise' resource patches within the terrestrial patch are taken into the account the picture of foraging behaviour within the terrestrial patch at Teouma becomes clearer.

Based on the discussion above, it is argued here that an alternative re-interpretation of the tortoise/fruit bat AI is required as follows; fruit bats likely offered greater foraging efficiencies initially, but increasing intensity of settlement at Teouma and intensification of fruit bat harvesting resulted in declines in abundance and a decline in foraging efficiency (see Chapter 7 for a more direct approach to tortoise and fruit bat resource depression). Fruit bat foraging efficiency appears to have declined to a level where net return rates were lower than those on offer to target tortoises in more distant patches, as distance-related costs of travel and transport became less of an issue. For this reason increasing mobility and the foraging for tortoises at greater distances occurred over time and space in response to resource depression of more proximal high-ranked resources. This is reflected by increasing tortoise abundance relative to fruit bat during the Lapita period (both cemetery and post-cemetery). This was followed by a sharp decline when tortoises became extinct around the time of the transition to the Early Erueti (Post-Lapita) period (Unit B1). For tortoises, this issue of mobility and central place foraging decisions is explored in more detail using much more detailed datasets in Chapters 7 and 8 from the perspective of changing population structures and anatomical skeletal element representation.

In sum, the tortoise/fruit bat AI indicates a significant shift from small game hunting of concentrated small game resources close to the site to spending more time hunting large-bodied tortoises in distant patches over time as protein/fat net returns from the former high ranked patch declined as predicted by the MVT. Despite this, fruit bat exploitation continued to be the most significant subsistence behaviour in the terrestrial patch over time.

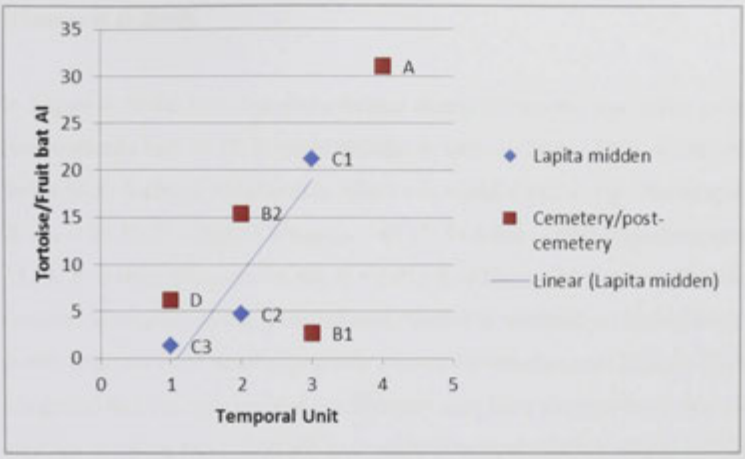


**Figure 6-12: Tortoise/fruit bat Abundance Index by temporal unit (Lapita midden: $X^2_{trend} = 180.61$, $P < 0.001$; $X^2_{departure} = 93.22$, $P<0.001$; cemetery/post-cemetery: $X^2_{trend} = 25.18$, $P<0.001$; $X^2_{departure} = 174.7$, $P<0.001$).**

Foraging efficiency was declining for small game and large game subsistence strategies presumably as a result of human exploitation within the terrestrial patch. It is possible that the decline in fruit bat exploitation could also have been a result of wider human activity including agricultural associated forest clearance. In Chapter 2 forest disturbances during the onset of human colonization in various locations in the Pacific were reviewed and found to be extensive but studies in Vanuatu have so far been limited largely to the island of Aneityum (Spriggs 1997). While localized vegetation disturbances could have impacted on food availability for tortoises locally, thus affecting local tortoise abundance, hunting tortoises in distant undisturbed forest patches would have been an option at some point in time. Tortoises have very different ecological adaptations than fruit bats, their generalized diet and adaptive digestive systems and their ability to occupy more disturbed habitats on the ground (Hansen et al 2010) suggests they are likely to be less affected by forest disturbances. But forest clearance by humans for shifting cultivation could have had some impact on arboreal nesting bird and bat species which could drastically affect local faunal abundances. Because small prey were unlikely to be exploited in great numbers at a distance from the Teouma site, due to prohibitive transport costs of small meat packages, localized forest clearances could drastically affect the proportions of fruit bat relative abundance. Human impacts on tortoises could also have resulted in much wider and far ranging ecological impacts as giant tortoises would have been an important part of the

ecosystem with regards to seed dispersal, nutrient cycling and vegetation adaptations (Hansen et al 2010).

In Figure 6-13 the idea that major habitat changes occurred was tested using the forest bird/wetlands bird AI (Σ forest bird/Σ(forest bird + wetland bird), which shows that forest birds declined significantly relative to wetland birds over time (Lapita midden $X^2_{trend} = 28.55$, $P < 0.001$; $X^2_{departure} = 49.31$, $P<0.001$; cemetery/post-cemetery: $X^2_{trend} = 15.28$, $P<0.001$; $X^2_{departure} = 6.06$, $P = 0.01$). It is likely that this was the result of declines in tropical forest environments relative to wetlands as indicated by preliminary pollen analysis from nearby Emaotfer swamp (Wirrmann et al 2011a). This study has suggested that the surrounding environment may have changed over time with coastal swamps receding from 3200 BP as a result of natural climatic changes while indications are that local rain forest changed to more open forest around 2800-2400 BP (Wirrmann et al 2011a). Based on Pacific environmental data, Spriggs (1986) and Hope (1996) both expect local swampland habitats to in fact increase as a result of human induced forest degradation. Any changes in the forest/wetland bird AI are therefore likely to be the result of an increase in wetland or swampy environments relative to forest environments. This supports the view that human environmental disturbances could have played an important role in the decline in local forest foraging efficiency rather than just resource depression as a result of human predation.

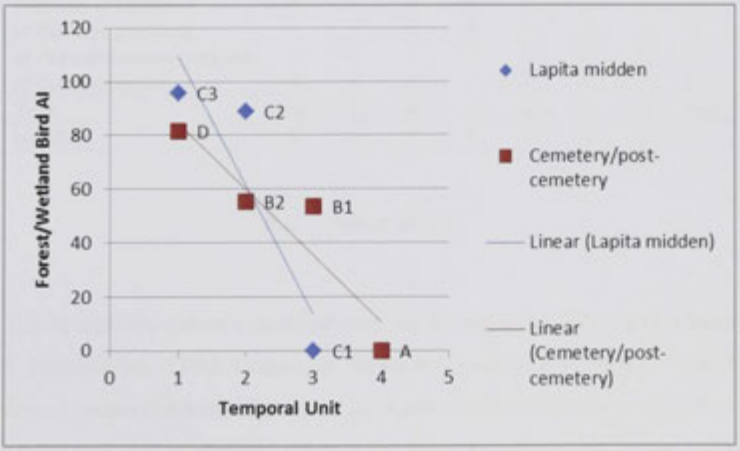


**Figure 6-13: Forest bird/wetland bird AI by temporal unit (Lapita midden $X^2_{trend} = 28.55$, $P < 0.001$; $X^2_{departure} = 49.31$, $P<0.001$; cemetery/post-cemetery: $X^2_{trend} = 15.28$, $P<0.001$; $X^2_{departure} = 6.062$, $P = 0.01$).**

## 6.2 Coastal Patch

The coastal patch is incomplete in its representation of the full range of taxa being exploited because fish and shellfish faunal remains were excluded from this analysis. The coastal patch is represented only by sea turtle and a few sea bird taxa, (see Table 6-4). Sea turtles represent the highest ranked taxa in this patch and (as discussed in Chapter 3) two types of sea turtle hunting strategies have been identified by Bird and Bliege-Bird (1997) based on the spatial patterning of sea turtle breeding and feeding behaviour. Sea turtles are known to be captured en masse in seasonal nesting colonies on the beach and these hunts typically are characterised by higher foraging efficiency with initially larger abundances available and easier capture. The second hunting strategy is targeting sea turtles along the reef edge as they are feeding alone or in small groups and these hunts are characterized by lower foraging efficiency due to lower turtle concentrations and harder and more dangerous search and capture costs.

**Table 6-4: Coastal patch taxa NISP and NTAXA by temporal unit**

| Taxa | C3 | C2 | C1 | D | B2 | B1 | A | Total |
|---|---|---|---|---|---|---|---|---|
| **Reptile** | | | | | | | | |
| *Cheloniidae* | 49 | 61 | 4 | 18 | 25 | 1 | 0 | 158 |
| **Bird** | | | | | | | | |
| *Sula leucogaster* | 0 | 1 | 0 | 0 | 5 | 1 | 0 | 7 |
| *Puffinus cf Bailloni* | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| *cf Puffinus pacificus* | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| *cf Pseudobulweria rostrata* | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| *cf Coenocorypha* | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| Total | 50 | 63 | 4 | 19 | 31 | 2 | 0 | 169 |
| NTAXA | 2 | 3 | 1 | 1 | 3 | 2 | 0 | |

### *6.2.1 Equitability*

The equitability values calculated from the Shannon (H) index are presented in Table 6-5. Because few NTAXA represent the coastal patch in the absence of shellfish and fish data, it makes this kind of analysis less useful with small sample sizes. In Figure 6-14 it can be seen that equitability values were lower and slightly declining indicating there was a specializing uneven focus on sea turtles during the Lapita midden units C3-C2. During the cemetery/post-cemetery temporal units, coastal patch exploitation became more even as equitability values increased sharply during the post-cemetery units B2

and B1 indicating increasingly generalist exploitation strategies and declining foraging efficiency over time in the coastal patch.

**Table 6-5: Coastal patch equitability and NTAXA index data by temporal unit**

| Unit | NISP | Shannon Index (H) | NTAXA | Equitability (E) |
|---|---|---|---|---|
| C3 | 50 | 0.01 | 2 | 0.14 |
| C2 | 63 | 0.16 | 3 | 0.15 |
| C1 | 4 | 0 | 1 | 0 |
| D | 19 | 0.21 | 2 | 0.3 |
| B2 | 31 | 0.58 | 3 | 0.53 |
| B1 | 2 | 0.69 | 2 | 1 |

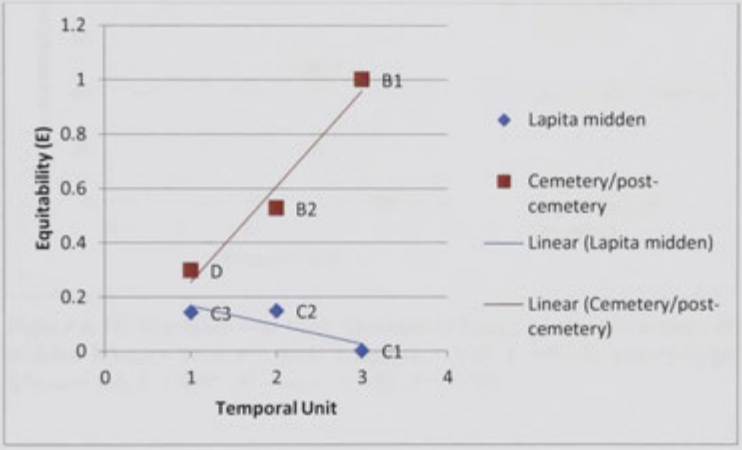


**Figure 6-14 : Coastal patch equitability values by temporal unit.**

### *6.2.2 Abundance Indexes*

Because sea turtle is the highest ranked taxa in the coastal patch, foraging efficiency is here measured using the sea turtle/sea bird AI, ΣSea turtle/(ΣSea turtle+ Sea birds) (Figure 6-15). The index indicates that sea turtle abundances were steady relative to sea birds during the Lapita midden units C3-C1, with no significant change (Lapita midden $X^2_{trend} = 0.04$, $P = 0.85$; $X^2_{departure} = 0.23$, $P = 0.63$). Quite clearly sea turtle dominates the coastal patch NISP early in the Teouma Lapita sequence indicating a specialization strategy which remained stable during the Lapita units D, C3, C2, C1. During the post-cemetery Lapita (B2) and Erueti (B1) midden, sea turtle relative abundance clearly declined as sea turtles become scarce but not significantly (cemetery/post-cemetery: $X^2_{trend} = 3.4$, $P = 0.07$; $X^2_{departure} = 0.31$, $P = 0.58$). This pattern indicates a shift from

nearby seasonal nesting colonies which would have returned high foraging efficiency to hunting smaller numbers of sea turtles on the adjacent reef at a lower foraging efficiency. From a qualitative point of view sea turtle decline appears to correspond to an increase in equitability to incorporate higher proportions of sea birds, and reflecting declines in foraging efficiency over time.

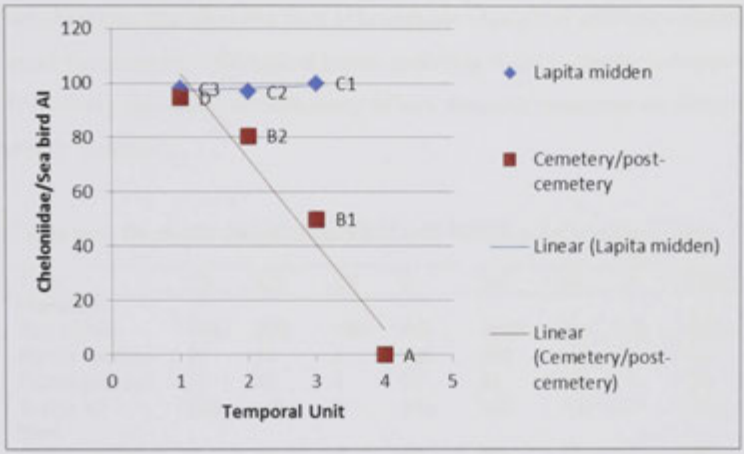


**Figure 6-15: Sea turtle/sea bird Abundance Index by temporal unit. (Lapita midden $X^2_{trend} = 0.04$, $P = 0.85$; $X^2_{departure} = 0.23$, $P = 0.63$); cemetery/post-cemetery: $X^2_{trend} = 3.4$, $P = 0.07$; $X^2_{departure} = 0.31$, $P = 0.58$).**

## 6.3 Domestic patch

This section focuses on management and foraging efficiency for domestic and commensal animals introduced during the earliest period of Lapita settlement at Teouma. Domestic patch taxa are arranged by temporal unit in Table 6-6. These include four species, domestic pig *Sus scrofa*, the Pacific rat *Rattus exulans*, the New Guinea Spiny Rat *Rattus praetor*, and the domestic chicken *Gallus gallus*. The most abundant domestic patch taxa by NISP were pig and rat, with much smaller quantities of chicken. Commensal animals are capable of surviving without human intervention but are also likely to be found in a range of habitats from coastal to terrestrial environments in addition to being close to human settlements. In Chapter 4 it was established that some domestic patch taxa such as pigs are commonly managed and thus do not need to be taken on encounter, while rats occur naturally in and near human settlements. For the purposes of this research it is assumed that some commensal animals are either

managed or harvested in close proximity to the Teouma site as part of the domestic patch (but see Chapter 7 for detailed account of Teouma pig husbandry practices and a discussion of rat predation). Commensal or domesticated animals are in effect allocated to the domestic patch not on the basis of an association with a specific feeding habitat or locality (where animals congregate or by a specific hunting method), but because it is a unique patch defined by the close symbiotic relationship of these introduced species with humans. The objective here is to measure changes in efficiency within this patch in much the same way that typical hunter gathering resource patches are measured. Effectively measuring the efficiency of how domestic resources are being managed and/or foraged.

**Table 6-6: Domestic patch taxa NISP and NTAXA by temporal unit**

| Taxa | C3 | C2 | C1 | D | B2 | B1 | A | Total |
|---|---|---|---|---|---|---|---|---|
| **Mammal** | | | | | | | | |
| *Sus scrofa* | 149 | 823 | 196 | 635 | 1850 | 241 | 36 | 3930 |
| *Rattus exulans* | 97 | 84 | 4 | 193 | 200 | 191 | 7 | 776 |
| *Rattus praetor* | 17 | 40 | 4 | 77 | 43 | 17 | 1 | 199 |
| *Rattus sp.* | 203 | 235 | 3 | 314 | 138 | 109 | 5 | 1007 |
| **Bird** | | | | | | | | |
| *Gallus gallus* | 6 | 54 | 5 | 82 | 66 | 13 | 6 | 232 |
| Total NISP | 472 | 1236 | 212 | 1301 | 2297 | 571 | 55 | 6144 |
| NTAXA | 4 | 4 | 4 | 4 | 4 | 4 | 4 | |

### *6.3.1 Equitability (Evenness)*

There is not much point demonstrating changes in diet breath for the domestic patch as a measure of changing foraging efficiency, because the taxa remain stable, with only four species present in all temporal units. As such there is little possibility of diet breadth expanding or contracting (Table 6-7). This is one of the expected strengths of the domestic patch which can provide a more predictable supply of resources. However the equitability index did indicate some changes in how taxa in this patch may have been managed or foraged (Table 6-7). In Figure 6-16 it can be seen that evenness declined quite sharply during the Lapita period units of C3, C2, C1 and post-cemetery Lapita period (B2) indicating an uneven more specialized use over time of a few domestic taxa (Pigs). However, evenness increased during the Post-Lapita settlement in temporal unit B1, indicating increasing generalization and a decline in efficiency.

**Table 6-7: Domestic patch equitability and NTAXA index data by temporal unit**

| Unit | NISP | Shannon Index (H) | NTAXA | Equitability (E) |
|---|---|---|---|---|
| C3 | 472 | 1.23 | 4 | 0.76 |
| C2 | 1236 | 1.02 | 4 | 0.63 |
| C1 | 212 | 0.37 | 4 | 0.23 |
| D | 1301 | 1.32 | 4 | 0.82 |
| B2 | 2297 | 0.73 | 4 | 0.46 |
| B1 | 571 | 1.24 | 4 | 0.77 |
| A | 55 | 1.07 | 4 | 0.67 |

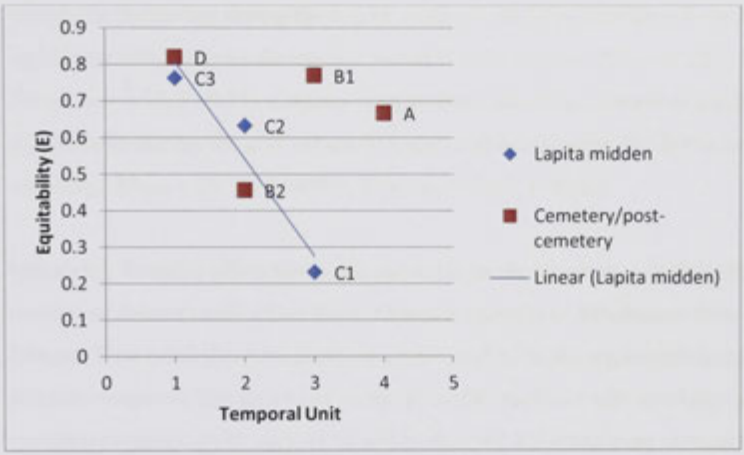


**Figure 6-16: Domestic patch equitability values by temporal unit.**

### *6.3.2 Relative abundance*

A change in the abundance of pigs over time is used here to infer changes in the intensity of pig production and by proxy changes in agricultural investment. Pigs were the most appropriate taxa for this task with well understood husbandry methods and costs and benefits. There is no ambiguity of human exploitation versus natural accumulation that afflicts rat remains associated with archaeological sites, and pig remains were also the most abundant taxa in the domestic patch, thus providing useful sample sizes. Pig relative abundance increased quite significantly (Lapita midden $X^2_{trend} = 272.3$, $P < 0.001$) relative to other taxa during the early Lapita midden phase (C3-C1), indicating rapid intensification of pig production during this period (Figure 6-17). This may correspond to declining equitability and increasing specialization outlined previously. Pig production also appears to have continued to significantly increase from the cemetery (Unit D) to post-cemetery Lapita midden (Unit B2) but declined sharply

during the Erueti phase (Unit B1) (cemetery/post-cemetery: $X^2_{trend} = 17.59$, $P<0.001$; $X^2_{departure} = 509$, $P<0.001$). This signposts a potential shift in pig management structure at the transition from Lapita to Post-Lapita periods after the cemetery fell out of use. It suggests a more complex picture of pig husbandry over time than that indicated by other Pacific archaeological studies (e.g. West 2007; Kirch and Yen 1982; Rolett 1998).

Chicken/domestic patch relative abundance (ΣChicken/Σ(domestic patch NISP) fluctuates, increasing during the Lapita midden units C3-C2 (Figure 6-18) but with no significant linear change during this period (Lapita midden: $X^2_{trend} = 2.87$, $P=0.09$; $X^2_{departure} = 7.92$, $P=0.05$). Chicken relative abundance does, however, decline significantly during the post cemetery Lapita and Erueti units (B2-B1) (cemetery/post-cemetery: $X^2_{trend} = 25.72$, $P<0.001$; $X^2_{departure} = 5.07$, $P=0.02$).

Measuring foraging efficiency in the domestic patch, however, is problematic because a number of factors could affect domestic patch taxonomic abundances for a range of reasons. First of all there are question marks over what the pig/domestic patch index actually measures. Because most of the domestic patch is made up of pig and rat vertebrate remains (with only some chicken), what it is measuring is essentially changes in pig abundance relative to rat abundance. This is reflected in the symmetrically opposite pattern in the rat/domestic patch relative abundance (ΣRat/Σ(domestic NISP) in Figure 6-19. As pig increased during the Lapita midden (C3-C1) phase, rats decreased significantly (Lapita midden $X^2_{trend} = 304.24$, $P < 0.001$). Rat also declined from the cemetery unit D to the post-cemetery Lapita midden unit B2 before increasing during the Erueti period (B1) (cemetery/post-cemetery: $X^2_{trend} = 4.87$, $P = 0.03$; $X^2_{departure} = 498.11$, $P<0.001$). The pig/domestic patch relative abundance is in effect either measuring changes in pig production intensity versus human foraging efficiency for rats or pig production versus natural rat population fluctuations or a combination of both. The archaeological evidence discussed in Chapter 3 suggested that Teouma rat remains represent a mixture of natural mortality and consumption. Either way the index is likely measuring pig production relative to rat abundance in the nearby environment over time.

Another issue to consider, which may influence domestic patch relative abundance, is natural changes in the environment as a result of climatic variability. Climate in the tropics is not likely to have changed much in any consistent direction in only 200-300

years of settlement at Teouma, but rather it is likely to have fluctuated with ENSO and other short climatic cycles discussed in Chapter 2. The rapid build-up of the deposits does not close off the possibility that these cycles could have affected pig and rat abundances during the course of the short lived temporal units. Climatic data is not available in enough detail to elaborate such a link, however, it is likely that changes in climate would have affected the abundance of both taxa equally. Hence any changes in faunal relative abundance over time are likely to be the result of human agency with regards to pig management strategies and rat interactions.

Another problem to consider is using size to rank taxa in the domestic patch. Using this rationale it can be expected that pigs with their large body size and propensity to mature quickly would be ranked the highest followed by chickens, the New Guinea Spiny rat, and lastly the smaller Pacific rat. But this is not taking into account costs involved in pig production compared to the potential for large numbers of even faster maturing rats to be mass harvested using techniques mentioned in Chapter 3. Rats are likely to have very few costs associated with pursuit considering traps and snares are usually used, as well as little travel and processing costs. The problem is similar to that with the tortoise/fruit bat AI where the net return rate differences between pigs and rats are unknown.

The pig/domestic patch index measures changes in relative abundance, so pig abundance could appear to be increasing in intensity but actual pig production may in reality have been declining because other taxa were simply declining at a faster rate. This occurred during the Tikopia sequence when all faunal remains including pig declined by temporal unit but pigs increased relative to local foraged resources (Kirch and Yen 1982). Such an association is difficult to assess in the Teouma fauna because of the disparate sample sizes per temporal unit. But overall faunal abundances were declining by the upper post-cemetery Erueti midden deposits as these became sparser.

As discussed in Chapter 4 the biggest problem with predictions of pig exploitation using OFM is that humans manage pigs for a variety of reasons both dietary and cultural. Fluctuating pig abundances could be the result of single events such as ritual festivals (see Chapter 4 for costly signalling discussion) rather than consistent subsistence based protein and fat maximization. The prohibitive costs of intensive pig production make pigs a focal point for wealth creation and social stratification. If pigs were used as costly signalling demonstrations of higher social value, then the main objective for pig

production and changes in pig relative abundance could be interpreted completely differently. It would instead be viewed as changing levels of social stratification which are likely to have been increasing during the cemetery phase, with increases in pig relative abundance. It may have declined during the post-cemetery units. Either way, increases in pig abundance will still represent declines in foraging efficiency because of the high costs of intensified pig production from exponentially increasing labour inputs the more pigs that are managed. Understanding how pigs were managed at Teouma, and the reasons why, is explored further in Chapter 7 using demographic reconstructions of pig mortality.

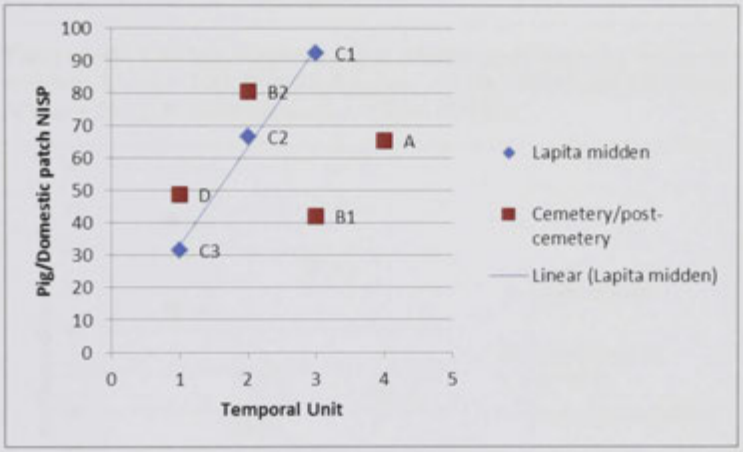


**Figure 6-17: Pig/domestic patch relative abundance by temporal unit (Lapita midden $X^2_{trend} = 272.3$, $P < 0.001$; cemetery/post-cemetery: $X^2_{trend} = 17.59$, $P<0.001$; $X^2_{departure} = 509$, $P<0.001$).**

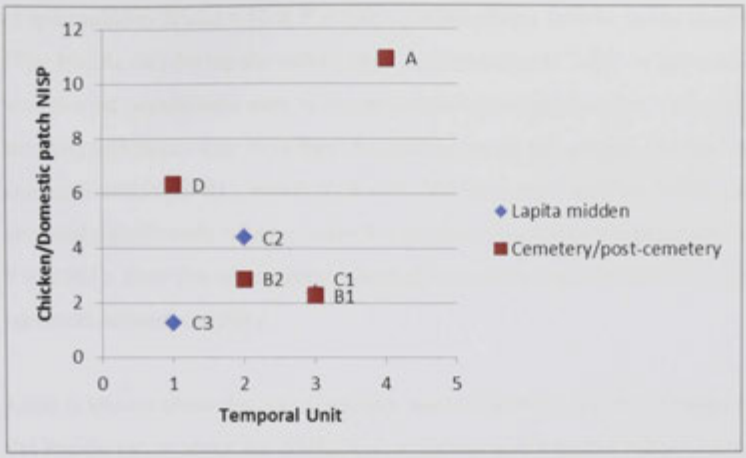


**Figure 6-18: Chicken/domestic patch relative abundance by temporal unit (Lapita midden: $X^2_{trend}$ = 2.87, P=0.09; $X^2_{departure}$ = 7.92, P=0.05; cemetery/post-cemetery: $X^2_{trend}$ = 25.72, P<0.001; $X^2_{departure}$ = 5.07, P=0.02).**

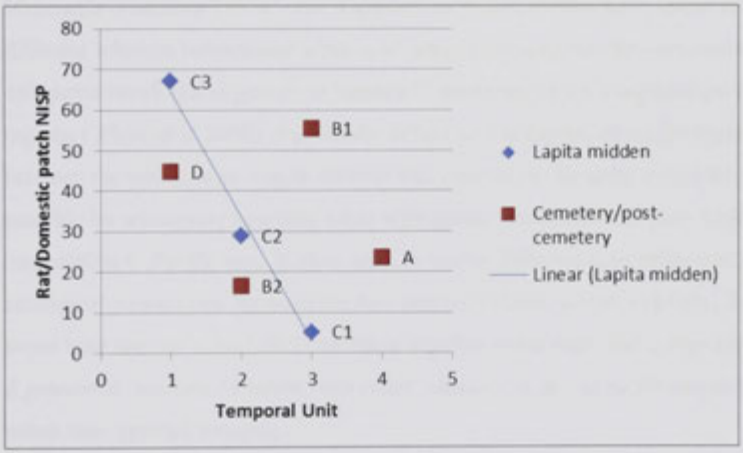


**Figure 6-19 : Rat/domestic patch relative abundance by temporal unit (Lapita midden: $X^2_{trend}$ = 304.24, P < 0.001; cemetery/post-cemetery: $X^2_{trend}$ = 4.87, P = 0.03; $X^2_{departure}$ = 498.11, P<0.001).**

Above it was noted that there was some ambiguity over how much of the rat assemblage is represented by natural population mortality versus human consumption. The Prey Choice Model predicts that the largest prey will be taken first on encounter to gain the maximum efficiency, once costs are subtracted. The *R .praetor*/*R. exulans* AI (*R .praetor*/*R .praetor* + *R. exulans*) (Figure 6-20) seeks to illuminate if any trends in potential foraging efficiency for rat exploitation existed. The *R. praetor*/*R. exulans* AI indicates that the larger *R. praetor* (New Guinea spiny rat) significantly increased

(Lapita midden $X^2_{trend} = 12.4$, $P < 0.001$) in abundance relative to the smaller *R. exulans* (The Pacific rat) during the early Lapita midden phase (C3-C1) of settlement when invasive rat populations were being established after introduction, indicating that rat foraging efficiency may have been increasing during this period. During the post-cemetery units (B2-B1), however, it was a different story and the New Guinea Spiny rat declined significantly relative to the Pacific rat (cemetery/post-cemetery $X^2_{trend} = 31.96$, $P < 0.001$). How this is interpreted depends on whether rats were mostly foraged or represent natural mortality.

Little is known about the ecological interactions between the New Guinea Spiny rat and the Pacific rat, or about the differences in habitat and foraging behaviour, and whether they occupied overlapping habitats. The New Guinea spiny rat is considered sympatric with other rat species including the Pacific rat and European-introduced rats in Island Melanesia (Flannery 1995a). But it appears to be less competitive, either as a result of different inherent behavioural aspects or rates of reproduction and has recently become extirpated on all island groups in Remote Oceania and much marginalized in other regions (White et al 2000). Significant differences in habitat or spatial separation between the two species would indicate that optimal rat foraging would have been possible by selectively targeting areas with greater abundances of New Guinea spiny rats relative to Pacific rats. If there were no major differences in behaviour, and ecological interactions between the two species overlapped quite closely, that would mean both species would likely be taken together using traps and snares and the *R.praetor*/*R. exulans* AI would thus reflect changes in the rat population over time rather than optimal foraging.

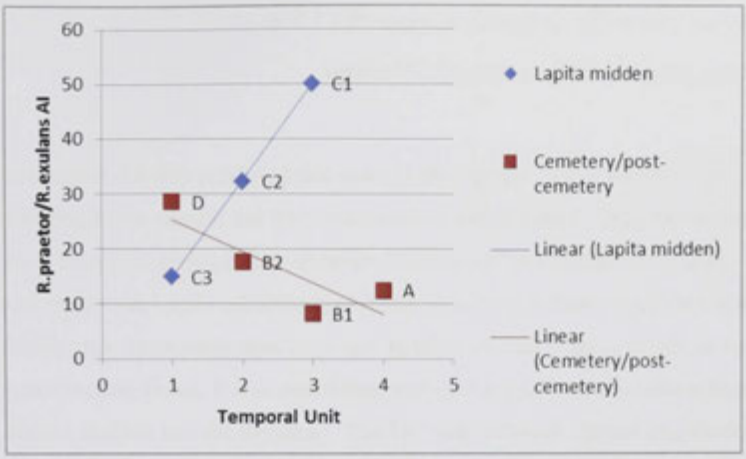


**Figure 6-20: *R. praetor*/*R. exulans* Abundance Index by temporal unit (Lapita midden $X^2_{trend} = 12.4$, $P < 0.001$; cemetery/post-cemetery $X^2_{trend} = 31.96$, $P < 0.001$).**

## 6.4 Inter-patch foraging efficiency

Unlike the fine grained Prey Choice Model and the coarse Patch Choice Model, the MVT and Central Place Foraging Model predict how long foragers will stay in a patch before moving to a new patch (see Charnov 1976; Orians and Pearson 1979). The MVT predicts that patches are abandoned in favour of other patches only once their net return rate falls below the average net return rate of all patches. Additional new resource patches could be added once the average return rate for all utilized resource patches declines to a certain point. AI's are also used to reflect foraging between proximal and distant resource patches, while demonstrating declining returns for central place foragers (Broughton 1999, 2002; Nagaoka 2002). These indexes typically show high net return resource patches declining relative to lower net return patches as a result of resource depression typically associated with declines in foraging efficiency. Foragers are then obliged to spend more time in resource patches with lower returns. This section explores this relationship between resource patch choice and resource patch intensification by measuring changes in foraging efficiency between resource patches, both proximal and distant, with varying and unknown net return rates.

### *6.4.1 Changes in foraging efficiency between the terrestrial patch and the coastal patch*

In Chapter 4 it was predicted that initially the highest returns would be provided by foraging in the coastal and terrestrial patches where initially faunal abundances would have been concentrated and net return rates would have been at their peak. As such we can expect the Lapita inhabitants to spend more time in these resource patches with the highest net return rates once costs and benefits are taken into account. In the terrestrial patch section above, it was established that the terrestrial patch could potentially be further divided into the proximal 'fruit bat' and 'tortoise' patches and more distant 'tortoise' patches. It was predicted that only large high ranked taxa would be exploited on encounter with increasing distance to the site due to the high travel costs involved and the need for optimal returns. Initially foraging was focused on proximal 'fruit bat' and 'tortoise' patches, but as net return rates in these proximal patches declined then time spent foraging in more distant 'tortoise' patches increased over time. In the coastal patch section it was demonstrated that the proximal coastal nesting sea turtles were also targeted during the early sequence but declined rapidly as these became depleted.

Examining changes in foraging efficiency between the terrestrial patch and the coastal patch is achieved using the sea turtle/tortoise AI (ΣSea turtle/(ΣSea turtle +tortoise) (Figure 6-21) and the fruit bat/sea turtle AI (ΣFruit bat/ΣFruit bat +sea turtle) (Figure 6-22) which measures changes in foraging efficiency between resources which were distributed at varying distances from the Teouma Lapita site. These taxa were chosen because they were the highest ranked taxa respectively within their resource patches and had the largest samples.

The sea turtle/tortoise AI (Figure 6-21) represents a clear shift from sea turtle exploitation to tortoise hunting over time and a dramatic decline in foraging efficiency. Initially, during the Lapita midden (C3-C1) phase, sea turtles were targeted in much greater abundances than tortoises because their proximal distance and concentrated abundances in predictable locations initially offered much higher foraging efficiencies. But over time the effect of human predation on these sea turtle seasonal nesting sites resulted in sea turtle abundance declining significantly relative to tortoise (Lapita midden $X^2_{trend} = 66.58$, $P < 0.001$). This indicates that coastal net return rates declined

relative to tortoise patches. Foraging efficiency within the sea turtle patch continued to decline significantly, but much less drastically, at low levels relative to tortoise hunting throughout the remainder of the cemetery/post cemetery phase of settlement from units D, B2-B1 (cemetery/post-cemetery $X^2_{trend} = 16.56$, $P < 0.001$). The sea turtle/fruit bat AI (Figure 22) demonstrates a significant decline of sea turtle abundance relative to the dominant fruit bat patch during the early Lapita midden period C3-C1 (Lapita midden: $X^2_{trend} = 4.86$, $P = 0.03$), and an insignificant decline during the cemetery/post-cemetery period (cemetery/post-cemetery $X^2_{trend} = 3.19$, $P = 0.07$).

In summary these data infer that as foraging efficiency declined in the proximal sea turtle and fruit bat patches, time allocation in more distant tortoise patches increased as distance, initially an important consideration in foraging decisions is likely to have become less of a factor in optimal foraging decisions. It follows that increasing distances were travelled to exploit tortoises for transport back to the Teouma site. This pattern is not likely to be the result of technological changes because large vulnerable reptiles are not associated with the use of technology in their acquisition. Increasing central place foraging for tortoises is inferred only from indirect measures, but it is explored in more detail in Chapter 8 using tortoise skeletal element abundance data.

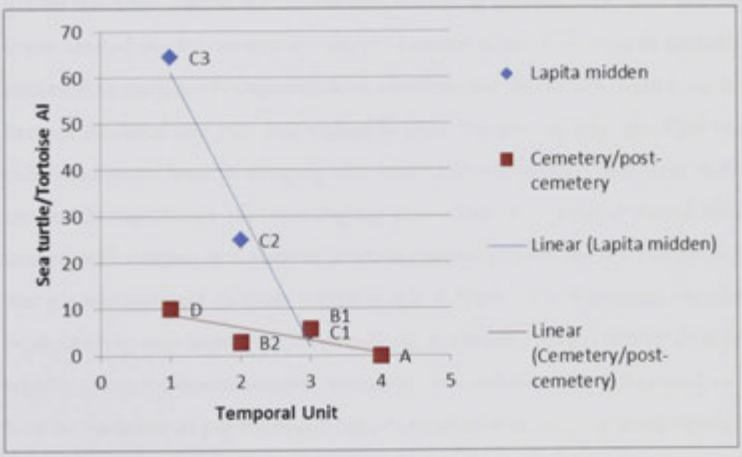


**Figure 6-21: Sea turtle/tortoise Abundance Index by temporal unit (Lapita midden $X^2_{trend} = 66.58$, $P < 0.001$; cemetery/post-cemetery $X^2_{trend} = 16.56$, $P < 0.001$).**

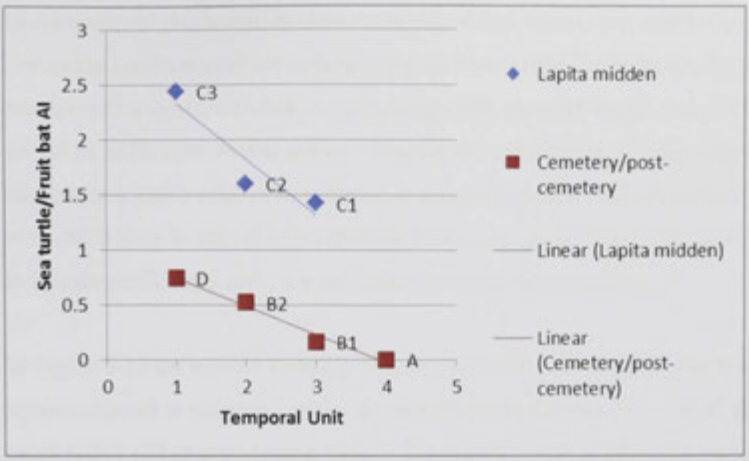


**Figure 6-22: Sea turtle/fruit bat Abundance Index by temporal unit (Lapita midden: $X^2_{trend} = 4.86$, $P = 0.03$; cemetery/post-cemetery $X^2_{trend} = 3.19$, $P = 0.07$).**

### *6.4.2 Changes in foraging efficiency between the domestic patch and coastal/terrestrial patches*

In Chapter 4 it was predicted that the highest returns for foragers would initially be gained from foraging in the coastal and terrestrial patches. The domestic patch would be lower ranked due to prohibitive labour investment costs. Animal husbandry was then expected to increase in importance as a protein and fat dietary source, as wild taxa became depleted and pigs and vegetable crops became established. This was expected to culminate in declines in foraging efficiency and intensifying increases in labour inputs. Inevitable trajectories of increasing pig production for whatever reason should be treated with caution as a number of ethnographic studies in New Guinea have shown that pig management systems within single villages have fluctuated from intensive pig production to non-intensive or outright pig husbandry abandonment depending on rapidly changing environmental, economic and cultural circumstances (see Hide 2003). Similar variation of pig management or abandonment also occurred during the historic period of Vanuatu (e.g. Deacon 1934) and prehistoric period elsewhere in the Remote Pacific (Clark et al 2013). Measuring foraging efficiency in the domestic patch is, therefore, more a case of measuring changes in pig management intensity, with increasing intensity associated with declines in foraging efficiency.

In the domestic patch section above it appeared that relative pig abundance did increase during the Lapita period but collapsed by the Post-Lapita Early Erueti phase. This was interpreted as a potential shift in pig management structure by the end of the Lapita period of settlement. In this section I explore this relationship between pig production in the domestic patch relative to foraging in coastal and terrestrial patches over time using inter-patch AI's to test OFM predictions of resource patch time investment and changes in foraging efficiency and prey utilization between these patches.

In Figure 6-23 the overall foraging efficiency between the domestic patch and the terrestrial patch is measured using the terrestrial patch/domestic patch AI (ΣTerrestrial patch NISP/ (ΣTerrestrial patch NISP + ΣDomestic patch NISP). This tracks the proportions of total identified terrestrial taxa NISP versus total domestic patch identified taxa. This index indicates a significant decline in terrestrial patch abundance relative to domestic patch during the Lapita midden units (C3-C1) (Lapita midden: $X^2_{trend} = 86.01$, $P < 0.001$) as well as a significant decline at the end of the Lapita sequence at Teouma during the post-cemetery Erueti midden unit B1 (cemetery/post-cemetery; $X^2_{trend} = 11.21$, $P = 0.001$; $X^2_{departure} = 136.41$, $P < 0.001$). These patterns represent a dramatic decline in foraging efficiency during settlement atTeouma as a result of human impacts on the terrestrial patch ecology and the establishment of horticultural systems.

Because the terrestrial patch is more diverse in terms of the spatial distribution of particular high ranked resources and the domestic patch is also diverse in terms of pig management versus rat exploitation/natural mortality, a more detailed measurement of foraging efficiency between these patches is provided. This was conducted by measuring changes in pig production against changes in the exploitation of high ranked resource clusters within the terrestrial patch. These clusters include proximal and distant fruit bat and tortoise patches which are used to measure shifts in foraging behaviour between these terrestrial patches and pig production. In Figure 6-24 the fruit bat/pig AI (ΣFruit bat NISP/ ΣFruit bat + pig NISP) measures this relationship between foraging within the high-ranked fruit bat proximal patch and pig production, where distance is likely to remain constant for both patches. Any shifts are, therefore, likely to reflect declines in fruit bat abundance and changes in pig management rather than distance related cost decisions. Either way it is predicted that foraging efficiency will decline as more time is allocated either to fruit bat harvesting intensification or pig production.

The fruit bat/pig AI indicates, much as in the terrestrial patch/domestic patch AI, that fruit bat significantly declined relative to pig in the Lapita midden (C3-C1) area (Lapita midden: $X^2_{trend} = 327.75$, $P < 0.001$), but also declined significantly from the cemetery unit D to the post-cemetery Lapita midden B2 where it remained stable during the Erueti period unit B1 (cemetery/post cemetery $X^2_{trend} = 44.71$, $P < 0.001$; $X^2_{departure} = 13.05$, $P < 0.001$). This is clear indication that foraging efficiency declined during both these periods. The Lapita decline corresponds to an increase in pig production seen in the domestic patch section but the post-cemetery decline corresponds to fruit bat resource depression at the end of the sequence rather than increases in pig production. In both cases foraging efficiency declined as either more labour was invested in pigs during the cemetery phase relative to fruit bat foraging as fruit bat abundances declined.

The tortoise/pig AI (ΣTortoise NISP/ ΣTortoise NISP + Pig NISP) measures changes in foraging efficiency between proximal and distant tortoise patches and pig production (Figure 6-25). Because tortoises are high-ranked taxa they are expected to be always taken on encounter and so are expected to decline over time. This was not the case in the terrestrial patch section because distance to tortoise patches were potentially changing, and so this index could be measuring changes in distance related costs versus the cost of increasing pig production. The tortoise/pig AI is consistent with this pattern of increasing significantly during the Lapita midden period (C3-C1) (Lapita midden: $X^2_{trend} = 12.34$, $P < 0.001$) as distance related costs of tortoise acquisition are more acceptable compared to the costs of pig production. Tortoise continues to increase relative to pig during the cemetery (Unit D) and post-cemetery Lapita midden (Unit B2). However, it dramatically declined during the Post-Lapita Early Erueti phase (B1) as the tortoise population appears to have collapsed and foraging efficiency declined around this transition period. For this reason there is no significant linear trend during this period (cemetery/post-cemetery $X^2_{trend} = 0.16$, $P = 0.69$), but there is a significant non-linear trend reflecting the fluctuating tortoise exploitation during this period ($X^2_{departure} = 104.73$, $P < 0.001$).

A similar comparison between the sea turtle patch and pig production in the domestic patch using the sea turtle/pig AI (ΣSea turtle/ΣSea turtle + pig) (Figure 6-26) reveals rapid and significant sea turtle declines relative to pig abundance during the Lapita midden (C3-C1) phase (Lapita midden: $X^2_{trend} = 63.3$, $P < 0.001$). This was followed by low levels of sea turtle predation declining significantly relative to pig production

during the cemetery/post-cemetery period (D, B2, B1) (cemetery/post-cemetery: $X^2_{trend}$ = 8.41, P = 0.004). Since Lapita arrival less time was spent foraging sea turtles in the coastal patch compared to managing pigs. This also reflects the rapid decline in foraging efficiency as a result of human impact on sea turtle populations rather than an increase in pig production over time.

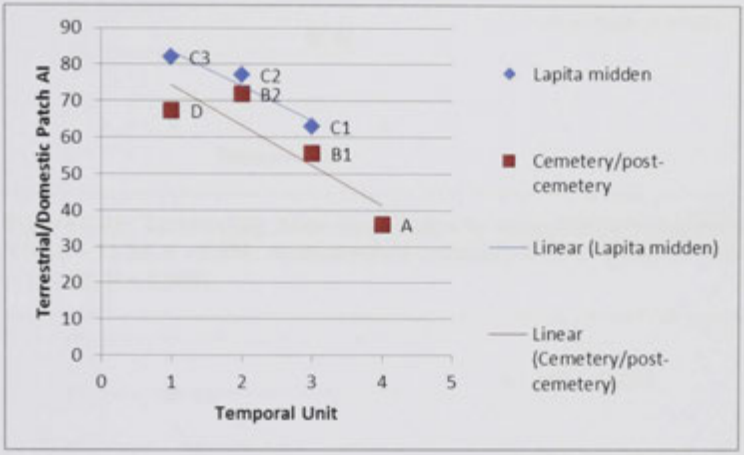


**Figure 6-23: Terrestrial patch/domestic patch Abundance Index by temporal unit (Lapita midden: $X^2_{trend}$ = 86.01, P < 0.001; cemetery/post-cemetery; $X^2_{trend}$ = 11.21, P = 0.001; $X^2_{departure}$ = 136.41, P < 0.001).**

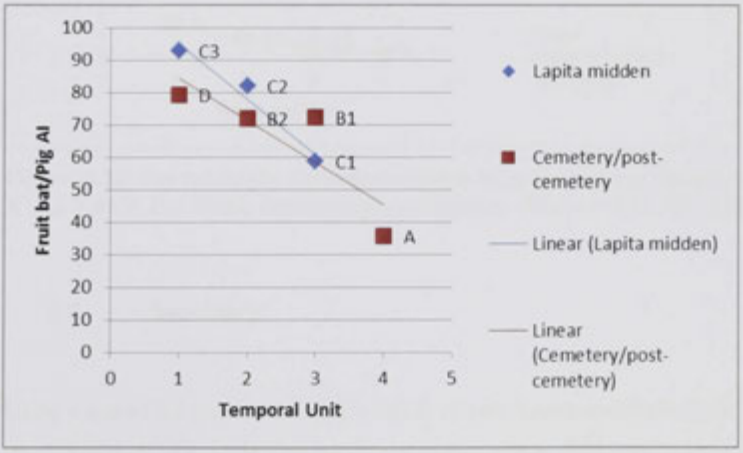


**Figure 6-24: Fruit bat/pig Abundance Index by temporal unit (Lapita midden: $X^2_{trend}$ = 327.75, P < 0.001; cemetery/post-cemetery $X^2_{trend}$ = 44.71, P < 0.001; $X^2_{departure}$ = 13.05, P < 0.001).**

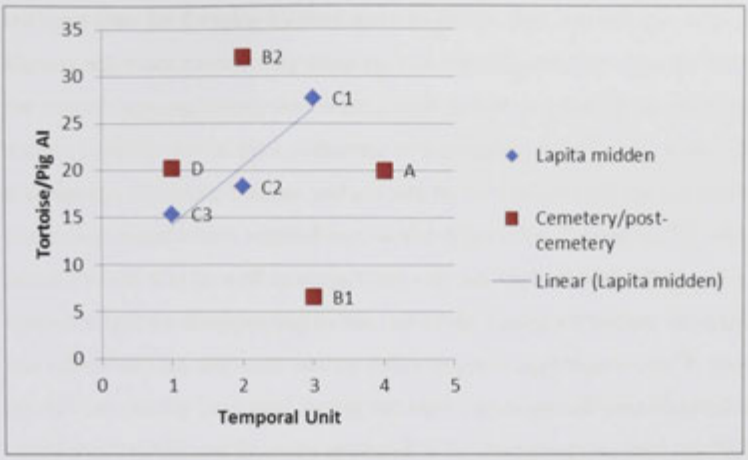


**Figure 6-25: Tortoise/pig Abundance Index by temporal unit (Lapita midden: $X^2_{trend} = 12.34$, $P < 0.001$; cemetery/post-cemetery $X^2_{trend} = 0.16$, $P = 0.69$; $X^2_{departure} = 104.73$, $P < 0.001$).**

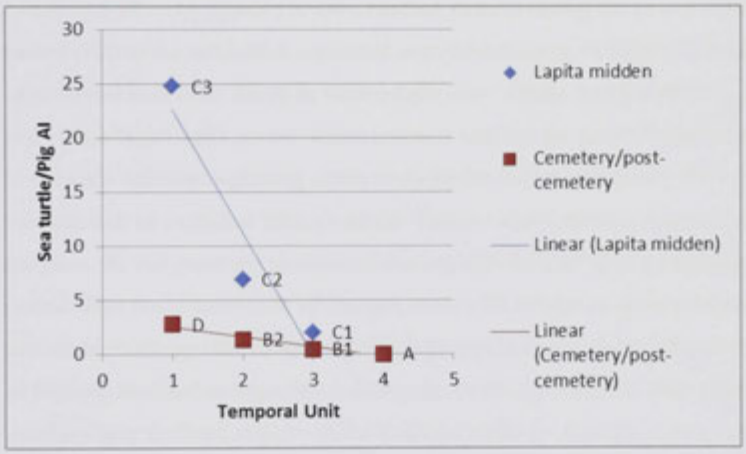


**Figure 6-26: Sea turtle/pig Abundance Index by temporal unit (Lapita midden: $X^2_{trend} = 63.3$, $P < 0.001$; cemetery/post-cemetery: $X^2_{trend} = 8.41$, $P = 0.004$).**

## 6.5 Summary

Using a quantified approach, explicit details of how Lapita and Post Lapita peoples structured their time exploiting various resources within different resource patches has been revealed at Teouma. Initially, during the early Lapita cemetery (D) and Lapita midden (C3-C1) phase of occupation, the proximal small game terrestrial patch, consisting mostly of fruit bats and the coastal sea turtle nesting patches, were allocated

the most time for foraging by the Lapita colonists. This was because they offered the highest net return rates during these periods. Small game fruit bats appear to dominate the assemblage suggesting they were a high ranked taxa and likely offered high net returns possibly due to mass collecting cost reducing efforts on concentrated bat abundances. Human predation and potentially human-induced habitat destruction and vegetation disturbances resulted in resource depression of proximal coastal sea turtles and terrestrial taxa as well as extinctions with ten bird, nine fruit bat, and at least one crocodile species disappearing by the end of the Lapita settlement. Fruit bat abundances were declining but sea turtle nesting patch resource depression was far more rapid. Pig production quickly increased during the early Lapita period as horticulture became established, settlement intensity appeared to be increasing and the large New Guinea Spiny rat was thriving and increasing in abundance relative to the Pacific rat.

Settlement intensity appears to have reached its peak during the post-cemetery Lapita period (B2) as the settlement expanded over the cemetery. A trend of increasing tortoise exploitation over time, likely in increasingly more distant tortoise patches, peaked at the end of this later Lapita period before tortoises reached the point of imminent extinction to coincide with the beginning of the Early Erueti Post-Lapita phase (B1). Sea turtles continued to be exploited throughout the Teouma post-cemetery sequence in very small numbers. At this point pig production also rapidly declined during the Early Erueti period. This could be a result of changes in the role of pigs in society coinciding with a decline in mortuary related feasting rituals practiced earlier during the cemetery period as feasting declined in importance during the Post-Lapita period. New Guinea Spiny rat numbers later declined relative to the smaller Pacific rat during the post-cemetery period.

These patterns indicate a complex range of subsistence decisions that mostly conform to OFM and suggest that Lapita culture was capable of adapting to periodic changes in ecological conditions. However, it also presents a picture of ecological destruction that humans seem incapable of avoiding in their attempts to make "optimal" economic decisions. The consequences are quite significant, and by the end of the Lapita period at Teouma, foraging efficiency and pig management in proximal and distal patches had declined. That the site was abandoned soon after this decline occurred has important implications for how settlement patterns were distributed across the Efate landscape during this period, and these will be discussed in Chapters 8 and 9.

# 7 Demography: Resource depression and pig husbandry

In this chapter the research aims focus on the temporal changes in animal demography which are estimated for two types of taxa; foraged and managed. Each type is subject to different sets of assumptions and, therefore, research aims. Demonstrating changes in demographic structure for the first group (foraged taxa) is aimed at directly establishing the link between changes in mortality profile to human predation and resource depression. Human predation is expected over time to result in declines in the mean age of hunted animal populations. Here I estimate more directly the impact that Lapita foragers had over time on the average demographic structure of the two most abundant terrestrial patch taxa at Teouma; tortoise and fruit bat, as well as demonstrating human impacts on rat populations.

The second group includes introduced domestic pigs, which work on a separate set of assumptions from foraged taxa. This is because, unlike the latter, they have the potential to be managed by humans in a way that renders encounter rates and search costs redundant. Understanding the demography of managed pigs could, therefore, shed some light on what husbandry strategies were being employed at Teouma. The existence of hunted versus managed pig populations has been demonstrated in this way using age estimates from archaeofauna data from prehistoric sites in the Pacific (Smith 2000; Walter 1998). Estimations of pig mortality patterns are also an essential part of OFM for the domestic patch with certain pig demographic profiles associated with optimal and non optimal utilization of pigs for meat (see chapter 3).

## 7.1 Resource depression

In Chapter 2 it was argued that resource depression and human influences on terrestrial bird and reptile extinctions during the colonization of the Pacific had only been casually linked or were not very well understood for some fauna. Previous historical ecology studies have been used to infer overkill patterns of faunal extinctions. However, it has been argued that other factors including habitat loss, the introduction of invasive mammals or climate change may have been responsible. There is, therefore, a need for

more direct measures of resource depression linked to human predation using demographic studies (Nagaoka 2012).

Resource depression has been measured directly by demonstrating declines in prehistoric demography of certain taxa in the Pacific, usually shellfish and fish (e.g. Allen 2012; Anderson 1981; Butler 2001; McAlister 2002; Morrison and Hunt 2007). Foragers usually target the largest individuals within a population, which are the adults, because they have the greatest amount of meat, and over time it is expected this will result in the reduction of adults within a population within a resource patch (Stiner 1991). Natural mortality profiles on the other hand typically are represented mostly by juveniles and older adults as individuals tend to die naturally in greater numbers within these age groups (Lyman 1987). But in some studies where declining relative abundances occurred, prey age did not conform to this pattern and actually remained stable or even increased over time (Broughton 1999, 2002; Butler 2001). Several factors other than resource depression may have a predictable impact on prey demography, including innovations in hunting strategy and technology, changes in prey behaviour in response to human hunting pressure and variation in seasonality of prey age and sex composition spatial distribution (Stiner 1991).

In Chapter 3 it was demonstrated that a number of bird, bat, and reptile species disappeared soon after the early Teouma sequence. In the previous chapter resource depression as a result of human predation was inferred indirectly by changes in prey diversity and relative abundance of high ranked versus low ranked taxa over time. More specifically it was suggested that fruit bat populations could be negatively affected by increasing local settlement intensity at Teouma. In this scenario tortoise populations appear to have become depleted at an increasing distance from the site as proximal resources became depleted. There was also a suggestion that rat populations suffered decline, particularly the New Guinea Spiny rat relative to the Pacific rat.

Differences in population turnover rates play a big role in human-prey interactions where intensive human procurement over periods of time, shorter than prey population regeneration time, can play havoc with the effectiveness of a population in regenerating itself and may reduce mean population age very quickly (MacArthur and Pianka 1967). Because tortoises fall into the category of slow maturing taxa with long reproductive lives, they are sensitive to declines in reproductive adults (Lambert 1982). Based on

size, because tortoises are high ranked taxa and slow maturing with low turnover rates, it was expected that they would suffer the effects of resource depression more quickly and dramatically than the higher-turnover, fast-maturing smaller fruit bats. Despite the potential for a quicker recovery rate for fruit bat populations after resource depression, low reproductive rates may count against their ability to withstand human predation. Rats with incredibly fast reproductive and maturation rates are probably the least likely taxa to be affected by human predation with turnover rates likely to recover quickly.

Here I measure the demographic structure of tortoise, fruit bat and rat populations using methods outlined in Chapter 5. Tortoise age is estimated using morphometric measurements. Mammal (fruit bats and rats) age is estimated using zones of post-cranial epiphyseal fusion that fuse at predictable stages (see Chapter 5). This is well established for rats although the chronology of fruit bat long bone fusion has yet to be determined definitively and was, therefore, estimated.

### *7.1.1 Tortoise demography*

Human predation of small tortoises has a long antiquity dating as far back as Mousterian culture in the Middle Palaeolithic in Spain, Italy and Israel (e.g. Blasco 2008; Seth and Tchernov 2002; Stiner et al 2000) as well as during Middle to Late Stone Age sites in South Africa (e.g. Klein and Cruz-Uribe 1983, 2000; Sampson 1998). A number of these studies demonstrated declines in small tortoise body size between lengthy time-averaged phases that spanned millennia (Klein and Cruz-Uribe 1983, 2000; Seth and Tchernov 2002, Stiner et al 2000). Stiner et al (2000) in particular attributed this to increasing human population pressure and intensification of tortoise harvesting. Tortoises can exist in high densities in the absence of human predation because they have low metabolic rates, high sub-adult and adult survivorship rates, and long life spans (Shine and Iverson 1995). However, the potential for human predation to affect their adult population structure makes them more vulnerable because they have high hatchling mortality, estimated for small tortoise species in the Mediterranean to be between 75-85% (Stiner et al 2000), long maturation rates, and females tend to be larger than males (Lambert 1982). This ensures that human predation would target the reproductive core of a tortoise population and combined, with the low hatchling success rate, could result in a rapidly declining population and average age. Stiner et al (2000)

modelled population dynamics (for small tortoises) in response to human predation and found anything over 4-7% annual decline of an adult population likely resulted in rapid population decline.

Tortoise demography for Teouma is shown in Figure 7-1 and Table 7-1 from measurements of humeri proximal shaft breadth mm (Measurement 4, M4 mm) combining all provenance units into a single sample to examine average tortoise demography. Average tortoise demographics strongly reflect a hunted population as individuals are concentrated around the mean humeri M4 breadth between 17-22mm (Figure 7-1) which is likely the size range for the adult population. Smaller individuals representing juveniles and larger older adults appear much less frequently. While it suggests a population selected for predation there may be some sexual dimorphism in the tortoise population with another peak between 23-27mm. A finer-grained temporal approach was carried out to investigate demographic change by temporal unit (Table 7-2, Figure 7-2), albeit with much smaller sample sizes. It shows a definite decline in mean tortoise size over time during the Lapita midden phase C3-C1, and a slight decrease from the cemetery phase (Unit D) to the post-cemetery midden (Unit B2), hinting at resource depression. Unfortunately this fine-grained temporal analysis is plagued by sample sizes too small for statistical analysis to be truly conclusive about changes in tortoise demography.

Changes in tortoise behaviour could also be responsible for changes in demography. Resource depression not only reduces prey abundance, it can also change prey behaviour in ways that exacerbate declining foraging efficiency (Charnov et al 1976). This does not appear to be the case with tortoises. They do not appear to form seasonal densities based on age structure, for example, like seals do. Nor do they appear to exhibit spatial separations based on gender, age or size. They could, however, potentially change their behaviour to inhabit more hidden locations within the forest interior. This would make them harder to find while increasing search time and travel costs and thus lowering encounter rates and foraging efficiency, reducing the effects of hunting pressure. Such evidence has yet to be found for changes in tortoise behaviour as a result of hunting pressure. Known tortoise defence mechanisms include their ability to keep still, hide and their armoured defence, but their sessile nature makes them easy prey to catch once located. Whether they actively avoid regions with higher predator densities is unlikely. Therefore declines in mean tortoise age over time on Efate Island

were likely to be the result of human predation rather than changes in tortoise behaviour.

**Table 7-1: Tortoise humeri m4 (mm) statistics, all spatio-temporal units combined.**

| Descriptive statistics | Humerus M4 (mm) |
|---|---|
| Mean | 20.21 |
| N | 104 |
| stdev | 4.6 |
| Max | 34.96 |
| Min | 9.22 |
| median | 19.72 |

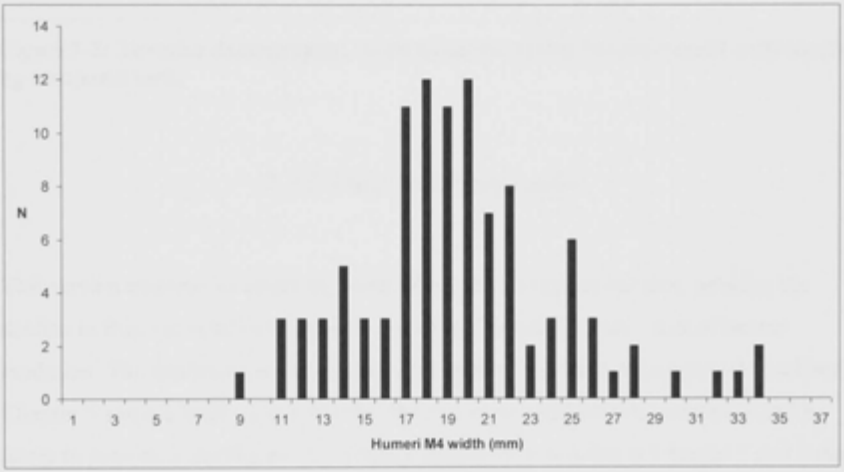


**Figure 7-1: Tortoise demography, all spatio-temporal units combined based on humeri m4 breadth (mm).**

**Table 7-2: Tortoise humeri m4 (mm) descriptive statistics by temporal unit. Note Unit A and B1 are not included due to a lack of measurable humeri present in this assemblage**

| Descriptive Statistics | C3 | C2 | C1 | D | B2 |
|---|---|---|---|---|---|
| Mean | 19.95 | 18.59 | 15.54 | 21.46 | 20.89 |
| N | 4 | 8 | 2 | 8 | 45 |
| Stdev | 2.12 | 3 | 1.25 | 7.27 | 5.21 |
| Min | 18.17 | 12.92 | 14.66 | 11.21 | 11.13 |
| Max | 22.96 | 22.87 | 16.42 | 34.96 | 34.05 |

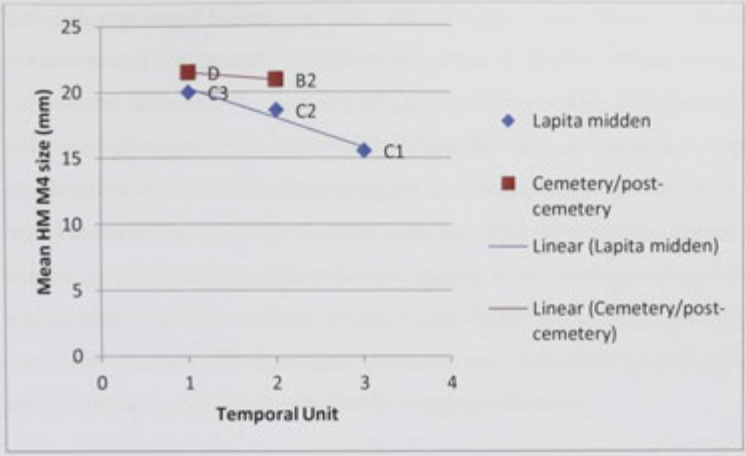


**Figure7-2: Tortoise demography, mean humerus (HM) Measurement 4 (M4mm) by temporal unit.**

### *7.1.2 Fruit bat demography*

This section attempts to establish, using demographic reconstructions, whether the decline in fruit bat relative abundance and diversity was a direct result of human predation. The methods used to estimate changes in fruit bat demography are outlined in Chapter 5 and are highly experimental, but this is the only known such study and is likely to provide a starting point for future studies. It was noted in Chapter 2 and 3 that little was previously known about prehistoric human interaction with fruit bats in the Pacific and what impact this interaction may have had on localized Pacific island fruit bat populations. The effects of modern hunting on fruit bats have been demonstrated to be quite substantial, placing bat populations under great pressure (Mickleburgh et al 1992, 2009; Chambers and Esrom 1989). Some Pacific bats have become extinct during the historic period (Helgen et al 2009; Mickleburgh et al 1992) and only a few extinctions have been recorded during antiquity (Hand and Mackie 2012; Koopman and Steadman 1995). Bats are very vulnerable to human activity because females, which reach sexual maturity around 18-24 months, have low birth rates of around only 1 per year (Pierson and Rainey 1990).

In Chapter 3 it was established that at least nine bat species disappeared during the early Teouma sequence. These species were not present in large numbers and so may not have been abundant locally in large colonies, possibly disappearing locally as a result of

forest clearance and habitat loss. They may also have been more vulnerable to environmental change and less able to repopulate from other islands, or to develop behavioural defences. The majority of Lapita and Post-Lapita fruit bat predation appears to have targeted only three species throughout the Teouma sequence, which started to dramatically decline in abundance relative to other terrestrial and domestic faunal resources near the end of the Teouma sequence. This indicates two things; the first is that the great abundance of these few bat species were roosting in large colonies nearby; and secondly that these colonies reached a threshold or ecological tipping point after cumulative periods of human exploitation and low birth rates that affected abundance and would have resulted in a decline in foraging efficiency.

Fruit bat long bone epiphyseal fusion data indicate very small amounts of un-fused early fusing skeletal elements (Figure 7-3) and only moderate amounts of un-fused late fusing elements (Figure 7-4). These data suggest mostly adult fruit bats and some sub-adult fruit bats were targeted by the inhabitants at Teouma over time with a perceptible but small increase in juveniles targeted during the post-cemetery period (Units B2-B1). Figure 7-5 plots the proportion of fused skeletal elements, both early and late, providing an indication of changes in the proportions of sub-adults and adults by temporal unit. This revealed no significant trend over time (Lapita midden: $X^2_{trend} = 0.04$, $P = 0.84$; cemetery/post-cemetery: $X^2_{trend} = 0.01$, $P = 0.9$). These data suggest negligible human impact on bat populations at Teouma, despite the variable pattern of fruit bat extinctions and resource depression inferred in Chapters 3 and 6.

A range of events could affect local fruit bat abundances without affecting age structures in a way that direct human predation is expected to. First, some fruit bat species, especially the non-endemic ones due to their fast maturation rate and widespread distribution, are able to redistribute to other locations in response to human activity and possibly develop other behavioural defences. Forest clearance was also indicated indirectly in Chapter 6 using the forest bird/wetlands bird AI and supported by tentative palynology data. This was probably due to agricultural related clearance, and this may have had a greater impact on fruit bat decline than direct human exploitation. It is also uncertain if rats affected bat populations as they had done with birds. These non-predation related disturbances could have had a greater impact on fruit bat abundances by forcing them to relocate to undisturbed forest areas. Fruit bat decline could also be the result of natural environmental disturbances such as cyclones (Pierson et al 1996)

and periodic climatic ENSO fluctuations in temperature and rainfall causing fluctuations in food availability and therefore bat abundances (Pierson and Rainey 1990). Even so, given what we know of modern fruit bat hunting pressures, it is likely that low reproductive rates typical of fruit bats would result in drastic declines in abundance as a result of prehistoric hunting. Other factors related to bat behaviour and ecology must also be considered responsible for the lack of change in the fruit bat age structure. Variations in the spatial distribution of prey by age and sex or changes in hunting methods could also result in prey age structures that do not meet expectations of resource depression over time (see Smith 1991).

With no indications of technological changes at Teouma, and simple capture methods still used by villagers in modern times, capture techniques are unlikely to have changed. Optimal strategies would have been focused on large nesting sites during the day when the mostly-nocturnal bats would be sleeping, making them easy to catch en masse. But adult bats foraging at night can also be caught using nets as they fly back to the roost at daybreak (Chambers and Esrom 1989).

Increasing predator-avoidance behaviour in response to human predation could result in patchy age-related spatial distributions for fruit bats (see Chapter 3). This has been observed for some ungulate mammal species on a seasonal basis where spatial separations of female and young groups occupy habitats during the mating off-season, with greater security from predators (see Broughton 2002). In modern times some fruit bat species in Vanuatu, especially the Pacific Flying Fox, have been known to fly off into separate camps, with females clustering in hidden inland locations to birth their young after the breeding season and thus making them significantly harder to find (Flannery 1995b). Bats tend to transition from juvenile to sub-adult/adult around the time they become volant after a couple of months so it is unlikely they would be seen until this transition. This would reduce the likelihood of juveniles being exploited as it is expected the mothers would stay with them until they could fly. Fruit bat exploitation by Lapita people at Teouma could therefore reflect the targeting of significantly audible breeding colonies by the coast during the summer, which consisted of mostly sub-adults/adults males and females with low encounter rates of juveniles.

**Table 7-3: Fruit bat long bone epiphyseal fusion, early and late fusing skeletal elements by NISP.**

| | C3 | | C2 | | C1 | | D | | B2 | | B1 | | A | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fusion stage | fused | unfused | fused | unfused | fused | unfused | fused | unfused | fused | unfused | fused | unfused | fused | unfused |
| **early fusing** | | | | | | | | | | | | | | |
| Humerus ds | 8 | 0 | 34 | 0 | 4 | 0 | 11 | 0 | 50 | 0 | 6 | 0 | 0 | 0 |
| Radius pr | 23 | 0 | 43 | 2 | 5 | 0 | 11 | 1 | 57 | 1 | 12 | 1 | 0 | 0 |
| Acetabulum | 3 | 0 | 13 | 0 | 2 | 0 | 9 | 0 | 24 | 0 | 8 | 0 | 0 | 0 |
| Tibia ds | 6 | 0 | 1 | 0 | 2 | 0 | 1 | 0 | 14 | 0 | 4 | 1 | 0 | 0 |
| Scapula | 33 | 0 | 46 | 0 | 11 | 0 | 15 | 0 | 72 | 0 | 9 | 0 | 0 | 0 |
| Inferior Phalange pr | 24 | 0 | 19 | 0 | 0 | 0 | 17 | 0 | 19 | 0 | 7 | 0 | 0 | 0 |
| Metacarpal pr | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 3 | 1 | 0 | 0 | 0 | 0 |
| Metacarpal 1 pr | 6 | 0 | 20 | 0 | 0 | 0 | 10 | 0 | 12 | 1 | 1 | 0 | 0 | 0 |
| Metacarpal 2 pr | 24 | 0 | 26 | 0 | 1 | 0 | 12 | 0 | 59 | 1 | 7 | 0 | 0 | 0 |
| Metacarpal 3 pr | 8 | 0 | 22 | 1 | 1 | 0 | 8 | 0 | 39 | 0 | 7 | 0 | 0 | 0 |
| Metacarpal 4 pr | 9 | 0 | 16 | 0 | 0 | 0 | 16 | 0 | 15 | 0 | 7 | 0 | 1 | 0 |
| Metacarpal 5 pr | 19 | 0 | 25 | 0 | 0 | 0 | 7 | 0 | 27 | 0 | 6 | 0 | 0 | 0 |
| Phalange pr | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 4 | 0 | 1 | 0 | 0 | 0 |
| Superior phalange pr | 21 | 0 | 34 | 0 | 0 | 0 | 13 | 1 | 39 | 2 | 11 | 2 | 0 | 0 |
| Superior phalange 1 pr | 8 | 0 | 23 | 0 | 0 | 0 | 12 | 0 | 0 | 0 | 8 | 1 | 0 | 0 |
| Inferior phalange ds | 22 | 0 | 19 | 0 | 0 | 0 | 19 | 0 | 21 | 0 | 6 | 0 | 0 | 0 |
| Metacarpal ds | 9 | 0 | 13 | 0 | 0 | 0 | 8 | 0 | 32 | 2 | 9 | 0 | 0 | 0 |
| Metacarpal 1 ds | 5 | 0 | 17 | 0 | 0 | 0 | 0 | 0 | 12 | 0 | 1 | 0 | 0 | 0 |
| Phalange ds | 4 | 0 | 2 | 0 | 0 | 0 | 5 | 0 | 5 | 0 | 2 | 0 | 0 | 0 |
| Superior phalange ds | 21 | 0 | 31 | 0 | 0 | 0 | 20 | 0 | 1 | 0 | 10 | 0 | 0 | 0 |
| Superior phalange 1 ds | 11 | 0 | 25 | 0 | 1 | 0 | 17 | 0 | 21 | 0 | 10 | 0 | 1 | 0 |
| Total | 264 | 0 | 429 | 3 | 27 | 0 | 215 | 2 | 526 | 8 | 132 | 5 | 2 | 0 |
| **Late fusing** | | | | | | | | | | | | | | |
| Femur pr | 25 | 0 | 29 | 0 | 4 | 0 | 23 | 0 | 91 | 1 | 19 | 0 | 2 | 0 |
| Femur ds | 4 | 3 | 4 | 0 | 0 | 0 | 3 | 1 | 10 | 6 | 5 | 0 | 0 | 0 |
| Humerus pr | 2 | 10 | 12 | 5 | 2 | 0 | 1 | 4 | 15 | 13 | 3 | 1 | 0 | 0 |
| Tibia pr | 9 | 1 | 22 | 0 | 1 | 0 | 10 | 0 | 47 | 1 | 8 | 0 | 0 | 0 |
| Radius ds | 5 | 1 | 13 | 1 | 2 | 2 | 8 | 4 | 28 | 9 | 3 | 4 | 0 | 0 |
| Total | 45 | 15 | 80 | 6 | 9 | 2 | 45 | 9 | 191 | 30 | 38 | 5 | 2 | 0 |

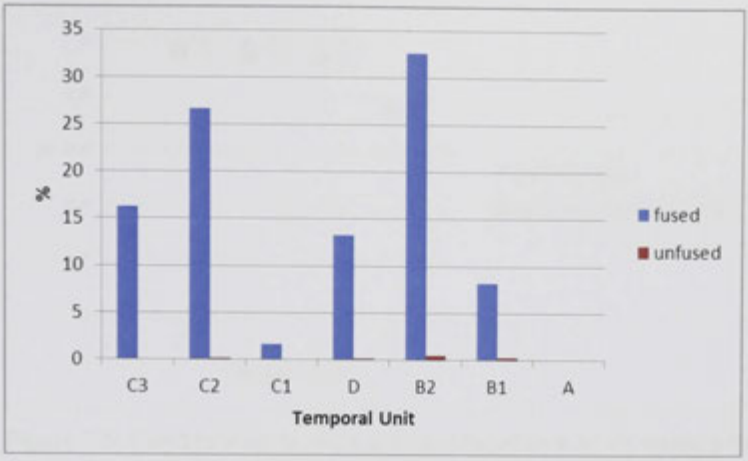


**Figure7-3: Early fusing fruit bat skeletal elements fused and un-fused by temporal unit**

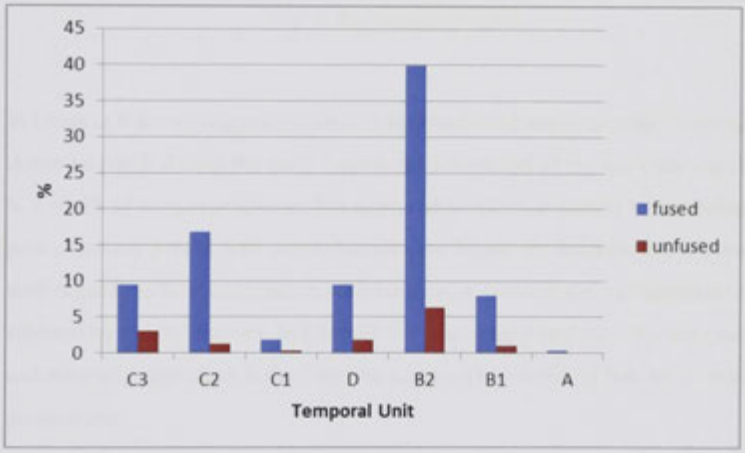


**Figure 7-4: Late fusing fruit bat skeletal elements fused and un-fused by temporal unit.**

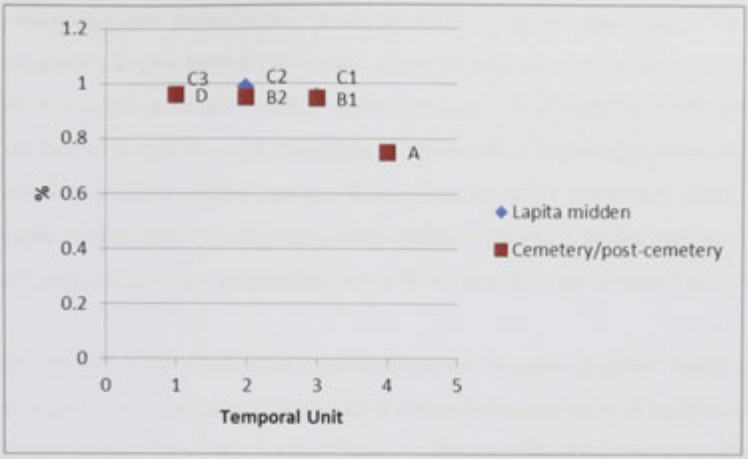


**Figure 7-5: Combined early and late fusing fused skeletal elements, adult/sub-adult proportions by temporal unit (Lapita midden: $X^2_{trend} = 0.04$, P = 0.84; cemetery/post-cemetery: $X^2_{trend} = 0.01$, P = 0.9)**

### *7.1.3 Rat demography*

In Chapter 6 it was suggested that rats declined in abundance relative to pigs in the domestic patch during the early Lapita midden period of the Teouma sequence, possibly as a result of human predation, but appeared to increase in relative abundance during the post-cemetery period with some fluctuations. However, because rats are ambiguous with regards to their association with humans, it is likely that rat abundance could be affected by natural factors. In Chapter 3 it was established that rats were both culturally and naturally deposited in the Teouma archaeological record but not in what proportions.

Understanding rat demography could potentially explain the nature of average human-rat interactions at Teouma, although such a study has not previously been attempted. Sustained human rat foraging behaviour is likely to result in declines in local rat demography over time. However, rats have very fast maturation and breeding rates and populations are therefore likely to recover very fast. Rat ages were estimated using established timetables of long bone skeletal epiphyseal fusion (outlined in Chapter 4).

Combining both *R. praetor* and *R. exulans* specimens, the Teouma rat demographics (represented by proportions of early and late fusing skeletal elements) indicate

consistently few juveniles and mostly adults by temporal unit (Figures 7-6, 7-7). This suggests a largely hunted population, although juvenile rat mortality rates in the wild are not well known and could potentially be low if food supply is sufficient. In addition, the lack of juveniles could potentially be the result of differential preservation and recovery of these smaller and less dense elements. Most importantly there are significant proportions of mature adult skeletal elements over the age of 33 months in all temporal units but proportions are at their highest in the cemetery temporal unit D.

In Figure 7-8 these data were combined into the "mature rat index" which essentially tracked the proportions of mature adult skeletal elements over 33 months of age by temporal unit. There was no significant rat demographic trend over time during the Lapita midden period ($X^2_{trend} = 0.17$, $P = 0.68$; $X^2_{departure} = 1.47$, $P = 0.23$). This is not surprising because initially Lapita foragers are not likely to target rats in great abundance because of the availability of higher ranked resources during a period of high foraging efficiency. Eventually resource depression in coastal and terrestrial resource patches is likely to have encouraged targeting of lower ranked rat resources as the proportion of mature adult rats significantly declined during the Teouma cemetery/post-cemetery sequence (cemetery/post-cemetery $X^2_{trend} = 43.49$, $P < 0.001$). This corresponds to an increase in rat proportions in the domestic patch outlined in Chapter 6 over the same period and strongly indicates that human predation had an impact on the local fast-maturing adult rat population resulting over time in fewer adults reaching old age after 33 months. This pattern is unlikely to be affected by preservation factors and is also unlikely to be the result of natural circumstances.

**Table 7-4: Rat post cranial skeletal epiphyseal fusion data, order of long bone age fusion after Dawson (1925).**

| | | C3 | | C2 | | C1 | | D | | B2 | | B1 | | A | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Element | age (days) | fused | unfused | fused | unfused | fused | unfused | fused | unfused | fused | unfused | fused | unfused | fused | unfused |
| **early fusing** | | | | | | | | | | | | | | | |
| Humerus ds | 31-42 | 32 | 0 | 32 | 0 | 1 | 0 | 50 | 0 | 46 | 0 | 44 | 0 | 0 | 0 |
| Radius pr | 83-92 | 3 | 0 | 1 | 0 | 0 | 0 | 5 | 0 | 4 | 0 | 4 | 0 | 0 | 0 |
| Acetabulum | 92 | 15 | 0 | 26 | 0 | 2 | 0 | 59 | 0 | 38 | 2 | 19 | 1 | 1 | 0 |
| Tibia ds | 92-98 | 17 | 4 | 18 | 3 | 1 | 0 | 59 | 3 | 47 | 14 | 34 | 6 | 1 | 2 |
| Scapula | 151 | 4 | 0 | 0 | 0 | 1 | 0 | 5 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| Total | | 71 | 4 | 77 | 3 | 5 | 0 | 178 | 3 | 136 | 16 | 101 | 7 | 2 | 2 |
| **Late fusing** | | | | | | | | | | | | | | | |
| Femur pr | 1006-1091 | 25 | 15 | 17 | 29 | 4 | 2 | 64 | 47 | 51 | 49 | 31 | 53 | 0 | 4 |
| Femur ds | 1135 | 6 | 34 | 7 | 30 | 1 | 2 | 32 | 61 | 27 | 69 | 19 | 58 | 1 | 3 |
| Humerus pr | 1135-1270 | 6 | 27 | 2 | 13 | 0 | 0 | 15 | 22 | 18 | 23 | 12 | 24 | 0 | 0 |
| Tibia pr | 1135 | 1 | 22 | 0 | 16 | 0 | 0 | 16 | 55 | 7 | 61 | 8 | 40 | 0 | 2 |
| Ulna pr | 940 | 9 | 0 | 3 | 0 | 0 | 0 | 11 | 0 | 5 | 0 | 2 | 0 | 1 | 0 |
| Ulna ds | 1135+ | 3 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 0 | 3 | 1 | 2 | 0 | 0 |
| Radius ds | 1135+ | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 2 | 0 | 0 |
| Total | | 53 | 98 | 29 | 88 | 5 | 4 | 139 | 188 | 108 | 206 | 73 | 179 | 2 | 9 |

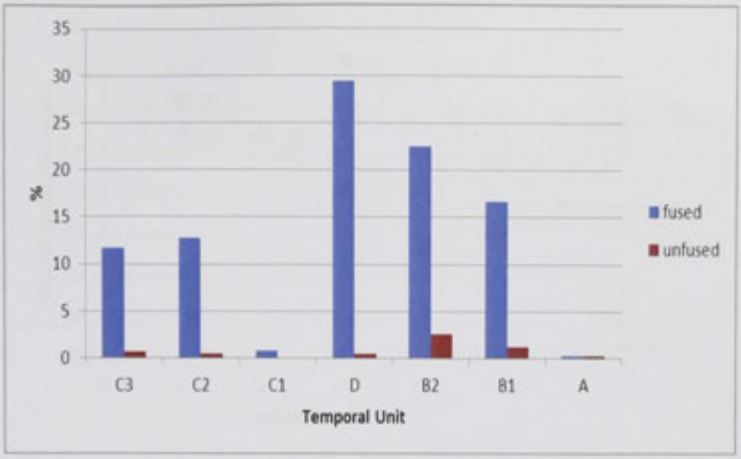


**Figure 7-6: Early fusing centres of rat skeletal epiphyseal fusion.**

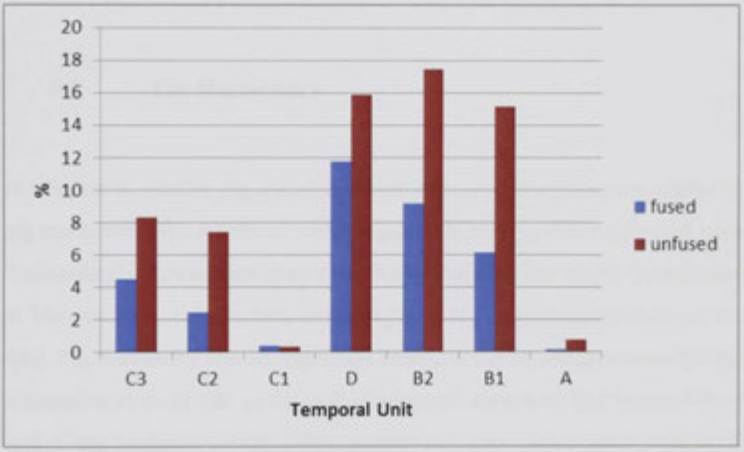


**Figure7-7: Late fusing centres of rat skeletal epiphyseal fusion.**

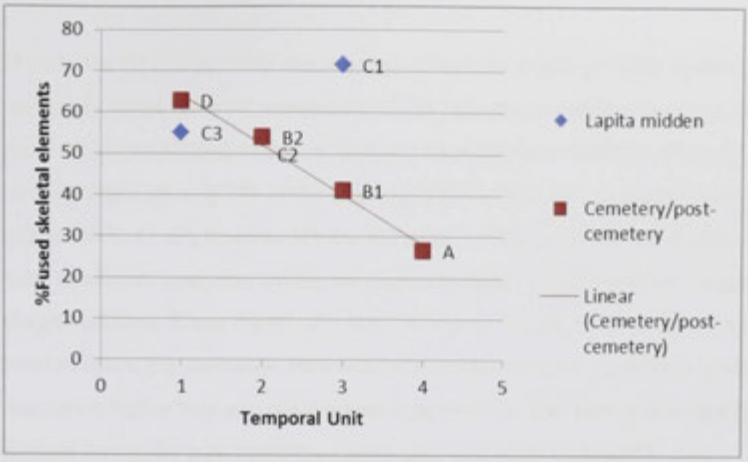


**Figure 7-8: Mature rat index by temporal unit. Combined early and late fusing fused skeletal elements (Lapita midden: $X^2_{trend} = 0.17$, $P = 0.68$; $X^2_{departure} = 1.47$, $P = 0.23$; cemetery/post-cemetery $X^2_{trend} = 43.49$, $P < 0.001$)**

## 7.2 Pig Husbandry

In Chapter 6, relative pig abundance was measured as a proxy for changing intensity of pig production, the results of which suggested changes independent of economic "rationality". This section goes some way to address Lapita pig management strategies at Teouma by re-constructing demography using age estimation and sex characterisation data. Pig husbandry was an important aspect of the Lapita economy, but previously was impossible to study due to the lack of adequate samples (see Chapter 2 for review of lack of pig husbandry data). Ethnographic accounts indicate that traditionally pigs are exploited in a variety of ways to achieve a variety of short and long term goals that incorporate dietary and socio-political values within fluid management systems (e.g. Hide 2003; Rappaport 1968). This is done using a range of husbandry strategies characteristic of how pigs are managed in terms of breeding, feeding and location. It was further argued that demographic profiles could shed some light on these management practices and goals. Predicted demographic profiles for kill patterns related to three broad pig management systems were laid out in Chapter 5 including hunting (prime adults 24-42 months), optimal dietary management (sub-adults/young adults 5-24 months), and social-political costly signalling (mature adults 42 months +). Chapter 5 also outlines the procedures used for demographic reconstruction including epiphyseal fusion, tooth eruption and wear, size and porosity and sex characterization.

Despite the typical survival and recovery issues for fragile juvenile skeletal material, young pig bones are well represented in the Teouma assemblage because of excellent preservation conditions and their high age identification visibility. Overall, infant pig remains make up only 3% of the total pig NISP at Teouma, while 15% are juvenile ( 6% infant MNE, 11.6% juvenile MNE). In Figure 7-9 the proportions of infant pig MNE were consistent over time during the Lapita midden (C3-C1) with no significant change (Lapita midden: $X^2_{trend} = 0.01$, $P = 0.92$; $X^2_{departure} = 0.94$, $P = 0.33$), indicating a steady level of infant pig mortality. However, within the cemetery (Unit D) pig infant mortality was much higher than any other spatio-temporal unit and there was a significant linear decline during the post-cemetery Lapita (B2) and Early Erueti (B1) units (cemetery/post-cemetery: $X^2_{trend} = 28.63$, $P<0.001$; $X^2_{departure} = 0.2.5$, $P = 0.11$). The proportion of Juvenile pig MNE (Figure 7-10) increases over time but not significantly for units C3-C1 (Lapita midden: $X^2_{trend} = 0.03$, $P = 0.87$) and the cemetery/post-cemetery units (cemetery/post-cemetery: $X^2_{trend} = 2.76$, $P = 0.1$). Combined, the proportions of infant and juvenile pig MNE under the optimal age of slaughter (0-6 months) show no statistically significant trend during the Lapita midden (C3-C1) period (Lapita midden: $X^2_{trend} = 0.01$, $P = 0.93$) but underage pigs declined significantly during the cemetery/post-cemetery units (cemetery/post-cemetery: $X^2_{trend} = 12.67$, $P<0.001$) as young pig survivorship improved over time (Figure 7-11).

The epiphyseal fusion data for long bones and vertebra is displayed for early fusing skeletal elements (Figure 7-12), middle fusing skeletal elements (Figure 7-13) and late fusing elements (Figure 7-14). The proportion of unfused early-fusing skeletal elements is highest in the cemetery units D and Lapita midden unit C1 but also prevalent in post-cemetery units B2 and B1 indicating high proportions of young pigs in these units. The proportion of middle-fusing elements, which all tend to fuse after the 24 month age mark, appear to be in equal proportions in most units. This indicates equal amounts of adults and sub-adults/young adults. Mature adults, as indicated by late-fusing elements around the 42 months and onwards mark, are present in only modest proportions between units C2-C1 during the Lapita midden, as well as post-cemetery units B2 and B1, and absent from the other units. These data suggest varied husbandry practices with a focus on young and adult pigs.

The tooth eruption data indicate a different story (Table 7-5; Figure 7-15). While infant teeth were not recovered from Teouma probably due to preservation and recovery issues, mostly sub-adult and young adult teeth were present with a good representation of juvenile teeth and small amounts of prime adult and mature adult teeth suggestive of an optimal dietary pig kill pattern.

Here I combine these disparate datasets, which offer overlapping and complimentary analysis, into six broad ontogenetic pig age classes of infant (0-1 months), juvenile (1-5 months), sub-adult (5-13 months), young adult (13-24 months), prime adult (24-42 months), and mature adult (42 months +) (Table 7-6; Figure 7-16). These data along with data indicating pig sex (Table 7-7; Figure 7-17) are used to characterize pig demography from which to interpret husbandry practices (see Chapter 5 for full details of methods). As predicted in Chapter 5 there were difficulties encountered by combining the different age reconstruction methods. The results indicate that pigs were being managed quite closely at Teouma throughout their entire life cycle for a variety of purposes since the earliest period of occupation. Large numbers of juvenile and infant remains were present in most temporal units especially the cemetery (D) as well as a range of sub-adult, young adult, prime adult, and mature adult individuals (Figure 7-16).

The ethnographic and archaeological mortality data provide some strong interpretations for pig herd management goals and strategies over time at Teouma. These strategies are concerned with breeding, population regulation, and social-economic integration of pigs within Lapita and Post-Lapita society during the colonization process in Vanuatu. Pig mortality (and therefore husbandry methods) at Teouma was quite varied with both short-term and long-term goals being practiced within a non-intensive management structure. The data suggests there was control over breeding of pigs in close proximity to Teouma - an indication of strict control of pig populations - as evidenced by the number of infant and juvenile remains. This was not a narrow focus on sub-adults and young adults for meat production or trade as seen from similar zooarchaeological studies at Pakea islet in the Banks Islands further north (Horton and Ward 1981), at Watom in the Bismarck archipelago (Smith 2000), or in the Marquesas in eastern Polynesia (West 2007; Rolett 1994, 1998). These latter interpretations of intensive optimal pig production as indicated by narrow optimal kill patterns for sub-adult and young adult pigs have been criticised by Hide (2003) as being more consistent with modern commercial piggeries than traditional varied management practices. There

were, however, at Teouma significant numbers of individual pigs within this age group throughout the sequence, suggesting that a number of pigs were killed for everyday meat consumption.

The high mortality for young pigs, a pattern not previously identified from a Pacific island archaeological site, can be interpreted with the aid of ethnographic information. Hide's (2003) review of studies of traditional village pig husbandry gives a clear picture of the lifecycle of young pigs being managed by villagers in a range of environments in New Guinea. High natural pig mortality rates (disease and malnutrition) or selective culling ranging between 10 to 74% of herd populations have been recorded during the first 9 months of life. The highest mortality was suffered by infant pigs in the first few weeks after birth and steadily reduced as the pigs aged. Natural pig mortality within Teouma herds suggests that at Teouma, malnutrition and disease could have been taking their toll as a result of concentrated herd populations combined with non-intensive feeding strategies. This may have required pigs to forage for most of their food in a restricted range with greater competition experienced than that by feral pigs. This is supported by the observation of linear enamel hypoplasia bands (see Dobney and Ervynck 2000) on some of the adult pig teeth at Teouma, an indication pigs suffered early developmental stress during weaning and limited nutrition during the first year of rapid growth. Such a pattern is typical of such systems in New Guinea and results in domesticated pigs being in a state of constant poor health compared to their feral counterparts.

If infant pigs were being culled before they reached the point of weaning, which was usually anywhere between 1 to 3 months (Hide 2003:88), it would indicate a management system not optimally aimed at maximizing pigs for meat production. It may indicate instead a system aimed at reducing labour costs associated with post-weaning feeding when young pigs would require substantially increased levels of hand feeding of vegetables. The advantage of maintaining a population at a certain level would therefore be in keeping the labour costs of production to an acceptable level. In Chapter 6 it was demonstrated that the pig population appears to have been increasing during the Lapita settlement at Teouma but declined during the Post-Lapita Early Erueti period. Regulating the population may have been a deliberate strategy to reduce competition between humans and pigs for plant resources, such as has been practiced in other parts of the Pacific at various times (Clark et al 2013). In this way additional

gardening labour costs could be kept in check to avoid any significant decline in foraging efficiency. Given that terrestrial patch protein/fat was abundant at Teouma during the colonization process, pigs may not have been essential for subsistence. Both natural mortality and selective culling of very young pigs would, therefore, suggest a non-optimal focus of pig management and a non-intensive production of pigs for food. Alternatively the larger proportion of infant remains within the cemetery unit D could be associated with symbolic ritual practices or funerary rites during which suckling pigs may have been sacrificed and/or consumed.

There is further evidence for non-optimal production of pigs at Teouma. A significant long term goal of pig management practiced at Teouma appears to have been associated with costly signalling, whereby the high costs associated with pig management could result in demonstrations of wealth and status where access to pigs is limited (e.g. Dye and Steadman 1990, Hogbin 1970, Pollack 1992). Perhaps this was also associated with mortuary rituals. The presence of a number of mature pigs over 42 months in age within deposits around the transition period between the cemetery Units C2-C1, D and post-cemetery periods in units B2, B1 is testament to evidence of high costs involved in long-term raising of pigs. Alternatively mature individuals could have been hunted as part of a mixture of managing domestic herds and hunting adults in the terrestrial patch.

Pig sex data (Table 7-7 and Figure 7-17) for Teouma suggests, like the mortality pattern, a varied management system involving both males and females. The data demonstrates that both males and females were killed in most temporal units but with no overall focus on either sex. Unit C3 and A had only female canines and the cemetery unit D had a higher proportion of males but otherwise pig sex exploitation was more or less even.

In summary, predictions of pig management within an OFM framework are problematic but by incorporating costly signalling theory it provided a stronger framework from which to examine changes in pig husbandry. The archaeological data supports ethnographic studies (see Hide 2003) which tell us that pig production does not follow a uni-linear evolution of increasing intensification but rather pig management is usually structured in ways that provide considerable dietary and social fluidity at the village and household level from intensification to de-intensification to outright abandonment. These ethnographic studies suggest that pig husbandry at Teouma included short term

goals in a continuous series of small scale subsistence-based events carried out usually at the household level during day-to-day living, characterized by large numbers of young pigs and small amounts of adults (Hide 2003). It also suggested that long term goals of social ritualistic feasting were practiced during the Lapita to Post-Lapita periods. High infant and juvenile mortality indicates a typical traditional village low intensity management system or social ritual activities.

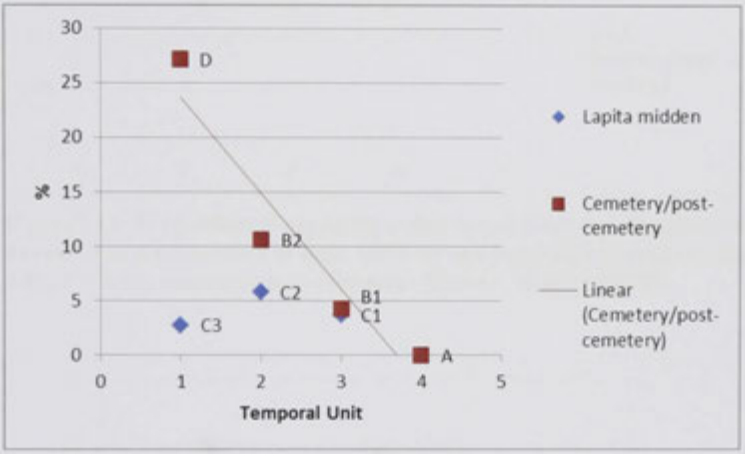


**Figure 7-9: Infant pig MNE as a proportion of total pig MNE by temporal unit (Lapita midden: $X^2_{trend} = 0.01$, P = 0.92; $X^2_{departure} = 0.94$, P = 0.33; cemetery/post-cemetery: $X^2_{trend} = 28.63$, P<0.001; $X^2_{departure} = 0.25$, P = 0.11)**

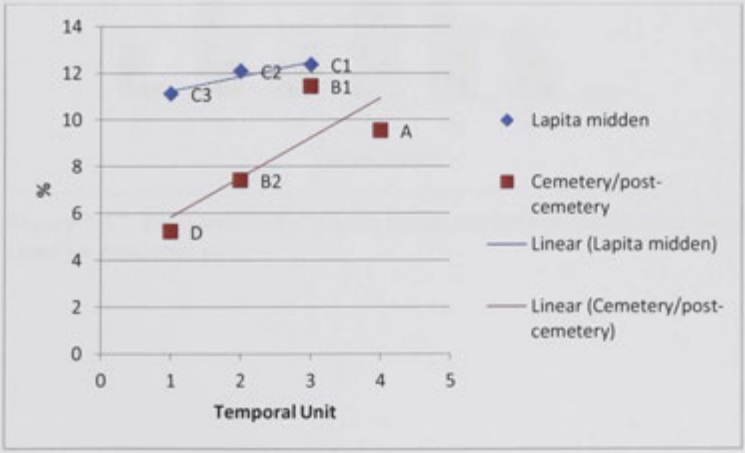


**Figure 7-10: Juvenile pig MNE as a proportion of total MNE by temporal unit (Lapita midden: $X^2_{trend} = 0.03$, P = 0.87; cemetery/post-cemetery: $X^2_{trend} = 2.76$, P = 0.1).**

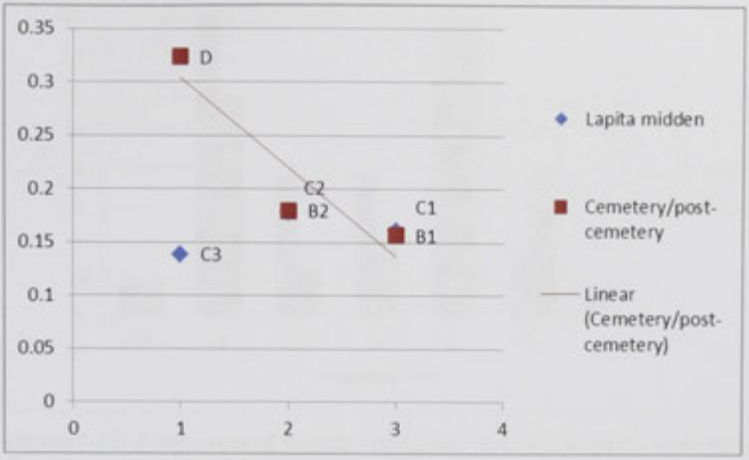


**Figure7-11: Proportion of pig MNE under optimal age for slaughter (Infant + Juvenile) as a proportion of total MNE by temporal unit (Lapita midden: $X^2_{trend}$ = 0.01, P = 0.93; cemetery/post-cemetery: $X^2_{trend}$ = 12.67, P<0.001).**

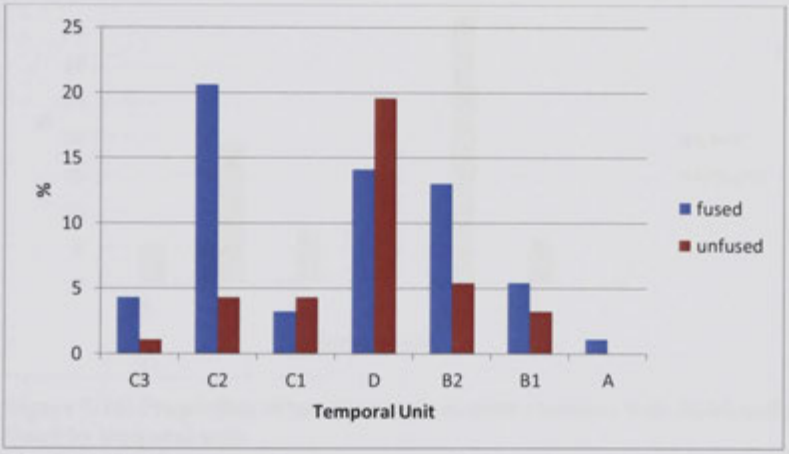


**Figure 7-12: Proportion of pig early fusing skeletal elements both fused and un-fused by temporal unit**

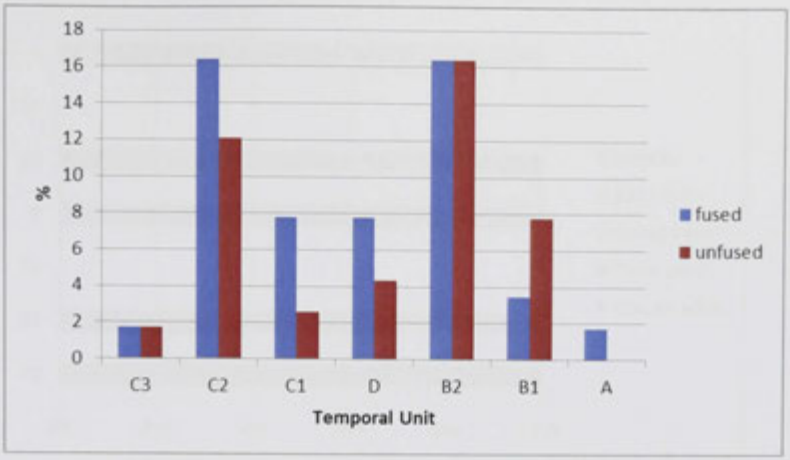


**Figure7-13: Proportion of middle fusing pig skeletal elements both fused and unfused by temporal unit.**

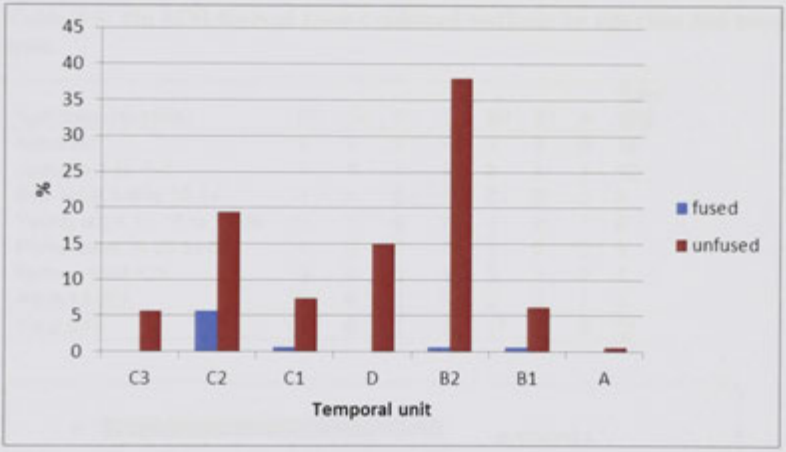


**Figure 7-14: Proportion of late fusing pig skeletal elements both fused and unfused by temporal unit**

**Table 7-5: Identified pig teeth combined temporal units by age class adapted from Rolett and Chiu (1994).**

| Age class | C3 | C2 | C1 | D | B2 | B1 | A |
|---|---|---|---|---|---|---|---|
| Juvenile | 0 | 1 | 0 | 13 | 2 | 0 | 0 |
| Sub-adult | 1 | 2 | 0 | 2 | 7 | 0 | 0 |
| Young adult | 0 | 1 | 0 | 7 | 30 | 0 | 1 |
| Prime adult | 0 | 0 | 0 | 2 | 3 | 0 | 0 |
| Mature adult | 0 | 1 | 0 | 1 | 1 | 0 | 0 |
| Total | 1 | 5 | 0 | 25 | 43 | 0 | 1 |

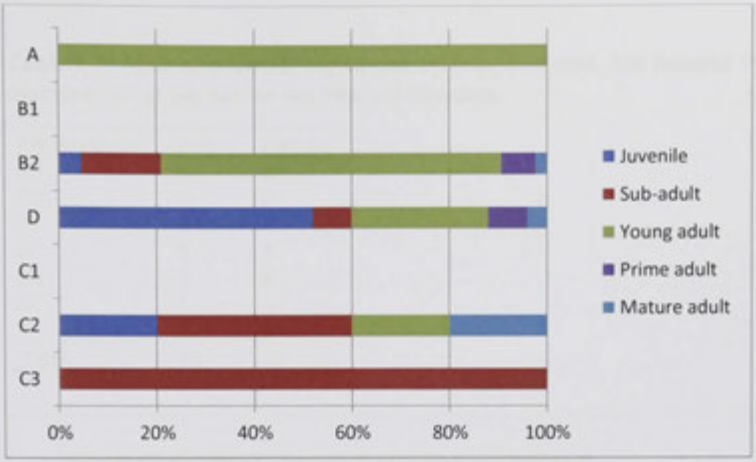


**Figure 7-15: Percentage of pig teeth by tooth eruption and wear stage age classes adapted from Rolett and Chiu (1994) by temporal unit.**

**Table 7-6: Pig MNI derived from combined methods by age class and temporal unit.**

| Age class (months) | C3 | C2 | C1 | D | B2 | B1 | A | Total MNI |
|---|---|---|---|---|---|---|---|---|
| Infant 0-1 | 1 | 2 | 1 | 5 | 5 | 1 | 0 | 15 |
| Juvenile 1 to 5-8 | 1 | 1 | 1 | 5 | 2 | 1 | 1 | 12 |
| Sub-adult 5-8 to 10-14 | 1 | 1 | 0 | 1 | 2 | 0 | 0 | 5 |
| Young adult 10-14 to 18-26 | 0 | 1 | 0 | 2 | 4 | 0 | 1 | 8 |
| Prime adult 18-26 to 42 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 3 |
| Mature adult 42+ | 0 | 1 | 1 | 1 | 3 | 1 | 0 | 7 |
| Adult 18-26+ | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| Total MNI | 4 | 6 | 3 | 15 | 17 | 3 | 3 | 51 |

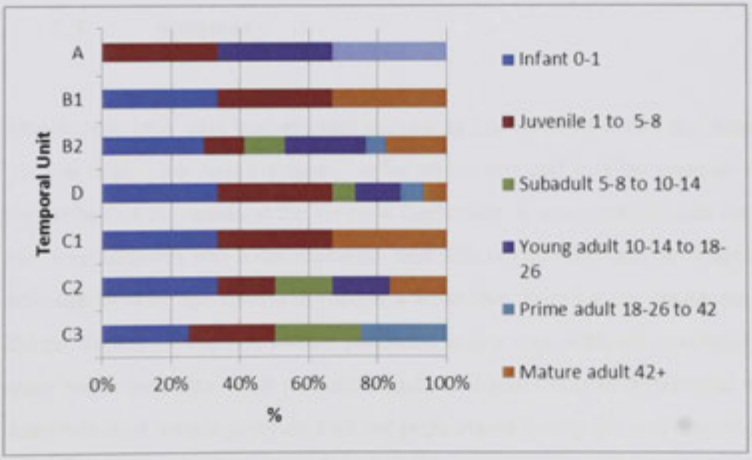


**Figure 7-16: Pig mortality methods combined and converted into proportionate age groups (months) by MNI and temporal unit.**

**Table 7-7: Male and female pig canine by temporal unit. See Schmid 1972 for descriptions of pig canine sex characterization.**

| Temporal unit | male | Female |
|---|---|---|
| C3 | 0 | 2 |
| C2 | 3 | 2 |
| C1 | 1 | 1 |
| D | 5 | 1 |
| B2 | 3 | 6 |
| B1 | 1 | 1 |
| A | 0 | 1 |
| Total | 13 | 14 |

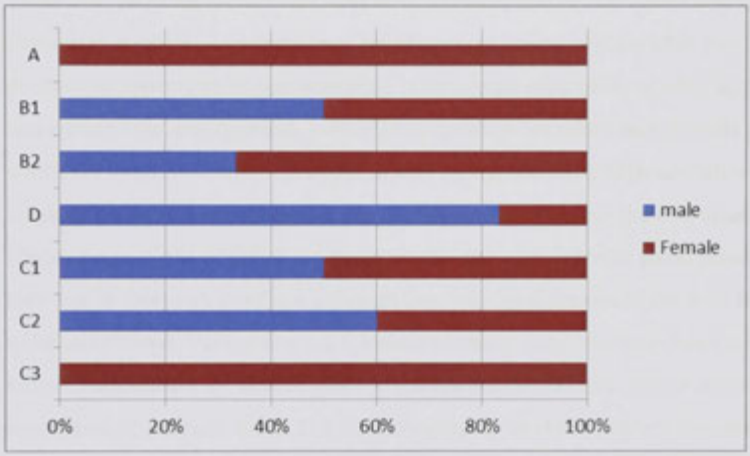


**Figure 7-17: Pig sex ratios by temporal unit**

## 7.3 Summary

The demographic data has revealed interesting and sometimes counter-intuitive findings on how human interactions directly affected tortoise and fruit bat populations exploited by the human occupants at the Teouma Lapita site. It was expected that the slow-maturing tortoises and faster-maturing fruit bats would both decline in age structure, although tortoise age should decline at a faster rate. Fruit bat age structures, however, did not appear affected by human predation in any way, with age structures appearing quite stable over time. This was attributed to the possibility of differential spatial age distribution of female-juvenile fruit bat populations during the non-breeding season. Such behaviour may have been developed in response to human predation and may have been the reason why some fruit bat species survived but many others did not.

Tortoise demography conforms to what is expected of a hunted population and predictions of decline in mean age over time. However, the decline does not appear as dramatic as expected in response to resource depression and is plagued by small sample sizes in some temporal units.

The demographic pattern for commensal mammals indicated some interesting patterns, suggesting a complex Lapita/pig interaction that was fluid and broad in its scope. Pig herds appear to have been managed and regulated in a non-intensive way by the Lapita inhabitants at Teouma during the course of the entire pig life cycle for a range of goals. These may have included household meat consumption of sub-adults and young adults through to social demonstrations at feasting events using mature adult pigs. Pig production appears to be non-intensive, with a large proportion of what appears to be non-optimal pig management, with high proportions of infant and juvenile pig remains which declined over time. This pattern may reflect naturally high mortality rates as a result of traditional non-intensive pig feeding methods during the colonization process. Higher proportions of infant pig bones in the cemetery deposits could possibly indicate their use in mortuary practices although the exact spatial association with burials has yet to be ascertained. Very young pigs, before weaning, may also have been culled to reduce competition for limited plant resources and to maintain labour investments in pig production at a certain level. The rat demographic mortality pattern indicated that the mature adult population age declined by temporal unit as a result of increasing direct human predation during the cemetery/post-cemetery period.

# 8 Animal Utilization: Mobility, Intensification and Social Stratification

This Chapter is concerned with the motivations behind animal utilization by prehistoric inhabitants at Teouma. Different motivations for animal exploitation are expected to include optimization to maximize protein and fat intake and/or symbolic/ritualistic and social stratification purposes. The theoretical framework and methods used to approach these issues are presented in greater detail in Chapters 4 and 5 respectively and only briefly need to be summarized here. In Chapter 6, changes in foraging efficiency as a result of resource depression were measured at the resource patch level. Here I add other proxy datasets for measuring changes in foraging efficiency by treating individual large bodied species as a resource patch using skeletal element representation and changes in butchery patterns. This chapter is therefore divided into two sections, each based on these two key datasets.

The first section focuses on skeletal element representation to investigate both optimizing and social aspects of Lapita culture as it rapidly transitioned to the Post-Lapita period at Teouma. This section is broken down into four sub sections. The first sub section investigates central place mobile foraging of large bodied turtles (tortoises and sea turtles) and butchery and transport decisions. These may have been made to reduce costs and improve foraging efficiency as proximal resource patches became depleted. Crocodiles were not included in this analysis because of the limited sample and more rapid decline. The second looks at non subsistence based turtle exploitation and a qualitative assessment of the presence of items made out of turtle shell. In the third, exploitation of birds of prey, not considered part of normal human diet, is investigated by comparisons of skeletal elements represented in the fauna with abundant likely diet-related bird taxa. Differential utilization between these two bird species types could reflect different motivations behind bird utilization. The fourth sub section investigates the quality of pig meat portions and their spatio-temporal distribution at Teouma to see if there is an indication of periods of ritual feasting.

The second section focuses on butchery patterns to determine if processing intensification increased over time in response to declining foraging returns. This analysis focuses first on tortoise butchery followed by pig butchery practices to see if

these modifications intensified over time and space. More specifically, changes in fragmentation, cut mark frequency, and bone fracture morphology data are presented.

## 8.1 Skeletal Element Representation

Skeletal element representation is calculated here for tortoise, sea turtle, bird and pig taxa using methods including Minimum Number of Elements MNE and Percentage of Minimal Animal Unit (%MAU) explained in Chapter 5.

### *8.1.1 Turtle Exploitation: Intensification and Mobility*

Only a few zooarchaeological studies incorporating skeletal element representation have been attempted to understand prehistoric tortoise exploitation. These were focused on small tortoises from archaeological deposits spanning the middle Palaeolithic in Europe (Blasco 2008) and the late Stone Age/historic period of South Africa (Sampson 2000). Sampson (2000) in particular compared tortoise assemblages from African Bushman settlements and kill sites as well as natural raptor roosts. The results indicated that the bushman associated deposits were distinct from the natural accumulations. They were characterized by a low representation of crania, mandibles, vertebrae and lower limb bones (Radii, ulnae, tibiae) and high proportions of upper limb bones (humeri and femora), as well as shell fragments. As small tortoises were not likely to be subject to transport and butchery decisions, it was argued that skeletal elements that were present in low proportions may have been differentially destroyed during preparation, cooking and consumption. This presumably may be due to these elements being less robust.

On Efate, giant tortoises and marine turtles, being large-bodied and high-ranked prey are predicted in Chapter 4 to have been differentially utilized in terms of skeletal element frequency between different terrestrial and coastal resource patches spatially over time. These "turtle patches" were likely distributed in clusters across the terrestrial and coastal landscape on Efate, each one with varying rates of encounter depending on ecological richness and state of depletion. If this was the case then mobility between these patches would have occurred as differences between resource patch net returns

became known to the foragers. Effects of resource depression on patch choice time allocation is explored here using MVT (Marginal Value Theorem) (Charnov 1976) and the Central Place Foraging Model (Orians and Pearson 1979) outlined in Chapter 4. Both predict more time spent in high value patches, which results in patch resource depression and declining foraging efficiency. They both also predict that as patches closer to the site become depleted patches further away may become increasingly used as distance related costs become less of an issue. This can be evidenced in archaeological studies by increases in abundance of high ranked prey as was documented in Chapter 6 with tortoise abundance during the Lapita period of Teouma settlement.

In Chapter 4 it was also discussed how increasing travel time - estimated to be the most significant distance related cost - can result in drastically decreased return rates and butchery and transport decisions are usually made to reduce these costs per foraging trip to improve foraging efficiency (Metcalfe and Barlow 1992; Bliege-Bird and Bird 1997). This often results in the anatomical body parts with the least nutritional utility being processed and discarded at the "kill" site and the higher ranked body parts are then transported back to a central base. Skeletal element representation may appear uneven as a consequence.

Tortoise skeletal element representation by %MAU (Figure 8-1) shows some variation between each temporal unit, with some temporal units having a broader skeletal representation than others. The data is too qualitative and not detailed enough to demonstrate changes in prey utilization. But it does suggest the tortoise skeletal element representation at Teouma is similar to that recorded by Sampson (2000) for small tortoises hunted in South Africa during the Late Stone Age with large proportions of humeri, femora, pelves and lower proportions of radii, ulnae, tibiae, crania, mandibles, foot bones and vertebrae.

To offer a more detailed analysis of butchery and transport decisions for large reptiles, I developed a method detailed in Chapter 5 that makes fewer assumptions and ranks skeletal elements into three ordinal meat utility categories of high, intermediate and low (see Figure 8-2). Relative proportions of these ranked categories were calculated from the sum of all MAU divided by the number of elements classified in each ranked skeletal element group (NELEMENT) by temporal unit (see Chapter 5 and Table 8-1

and 8-2 for description of data used to calculate tortoise and sea turtle meat utility respectively).

#### 8.1.1.1 Tortoise

The proportions of low-ranked (Figure 8-3) high-ranked (Figure 8-4), and intermediate (Figure 8-5) tortoise skeletal elements appear to fluctuate over time, reflecting changes in foraging efficiency. Two strategies aimed at maximizing optimal outputs in response to resource depression appear to have occurred at Teouma. The first involved making butchery- and transport-based decisions to reduce distance-related travel costs during a number of periods at Teouma. Secondly tortoise utilization intensified by incorporating a wider range of skeletal elements into the diet at Teouma over time.

The first strategy practiced at Teouma involved butchery decisions in distant patches to remove low ranked skeletal elements to reduce transport costs. Initially mostly high ranked skeletal elements were returned to the site in unit C3 as foraging efficiency was high and butchery and transport decisions were returning maximum efficiency. Low-ranked skeletal elements were present in very low proportions during all temporal units. During the Lapita midden period (and from the cemetery to post-cemetery-Lapita periods), distant tortoise patches became depleted. This resulted in forays into more distant patches as proportions of low ranked skeletal elements declined.

As central place foraging was occurring at increasing distances from the site, the second strategy of carcass intensification was increasingly employed to maximize returns from declining encounter rates with high ranked tortoises. The proportion of high-ranked skeletal elements declined from units C3-C1 as intermediate-ranked skeletal elements increased in proportion. Clearly transport decisions were declining in importance as the skeletal element representation, with the exception of low skeletal elements, broadened. This is reflected in a significant but negative correlation between increasing tortoise relative abundance (see Chapter 6) and declining tortoise high ranked skeletal elements during the Lapita midden period (C3-C1) ($X^2_{trend} = 35.62$, $P < 0.001$). This indicates a strong link between resource depression, carcass intensification and mobile targeting of distant tortoise patches. A possible explanation for the decline in high ranked skeletal elements over increasing distance could be the targeting of coastal tortoise populations

by Lapita settlors at Teouma using water craft to reduce distance costs and thus return increasing numbers of tortoises and a broader range of skeletal elements to the site.

### 8.1.1.2 Sea turtle

It was argued in Chapter 6 that sea turtle exploitation during the early Lapita cemetery phase of occupation was focused on nesting colonies, which resulted in resource depression and declines in sea turtle nesting colonies. Sea turtle carcass utilization trends appear to follow a similar pattern to that of tortoise with higher proportions of high-ranked sea turtle skeletal elements during the earliest period of occupation, which declined during the Lapita midden (C3-C1), as well as during the cemetery (D) and post-cemetery (B2-B1) periods (Figure 8-6). The decline in high ranked sea turtle skeletal elements and a corresponding increase in intermediate ranked elements (Figure 8-7), indicates an intensification of sea turtle carcass utilization in response to resource depression and declining foraging efficiency. Low ranked sea turtle skeletal elements declined initially during the Lapita midden period between units C3 and C2 indicating there was some attempt to reduce butchery costs. By the post-cemetery Lapita midden and Erueti temporal units, higher proportions of low-ranked skeletal elements (Figure 8-8) indicated that distance related costs were not an issue in sea turtle exploitation. During the Lapita period, as sea turtle nesting colonies declined, the need for intensive utilization is likely to have over-ruled these transport costs, which would have been minimized by canoe transport along the coast. Because later post-cemetery sea turtle foraging appears low intensity, it probably represents opportunistic hunting of sea turtles on the feeding grounds at the reef edge or in the Teouma harbour in close proximity to the settlement, rather than distant nesting sea turtle colonies. This represents a drastic decline in sea turtle foraging efficiency between the cemetery and post-cemetery periods, as hunting sea turtles in their feeding grounds at the reef edge requires more risky and difficult capture methods and greater search times with lower encounter rates (Bliege-Bird and Bird 1997).

### 8.1.1.3 Bone destruction processes

A limitation of this study is that bone destruction factors rather than bone transport decisions could reflect differential distribution of skeletal elements within an assemblage (Lyman 1994). Less dense bones tend to get destroyed first as a result of

carnivores, butchery, and post depositional factors (Lyman 1985:233). At Teouma carnivore and rat gnawing as well as butchery marks are present on small percentages of the bones, but most of the faunal remains had suffered post depositional bone breakage. Studies often use skeletal element density data plotted against skeletal element representation (Lyman 1982, 1984, 1985, 1994), with high correlations suggesting that bone destruction is the cause. Questions remain, however, about the variability in density values at the inter- and intra-species level and hence the general accuracy of such studies (Ioannidou 2003; Lyman 1984). No such data are currently available for large reptiles and this lack of analysis precludes the possibility of ruling out bone destruction as a significant factor influencing skeletal element patterns. For the present it is assumed that all skeletal elements are destroyed at an equal rate and therefore should reflect cultural deposition patterns.

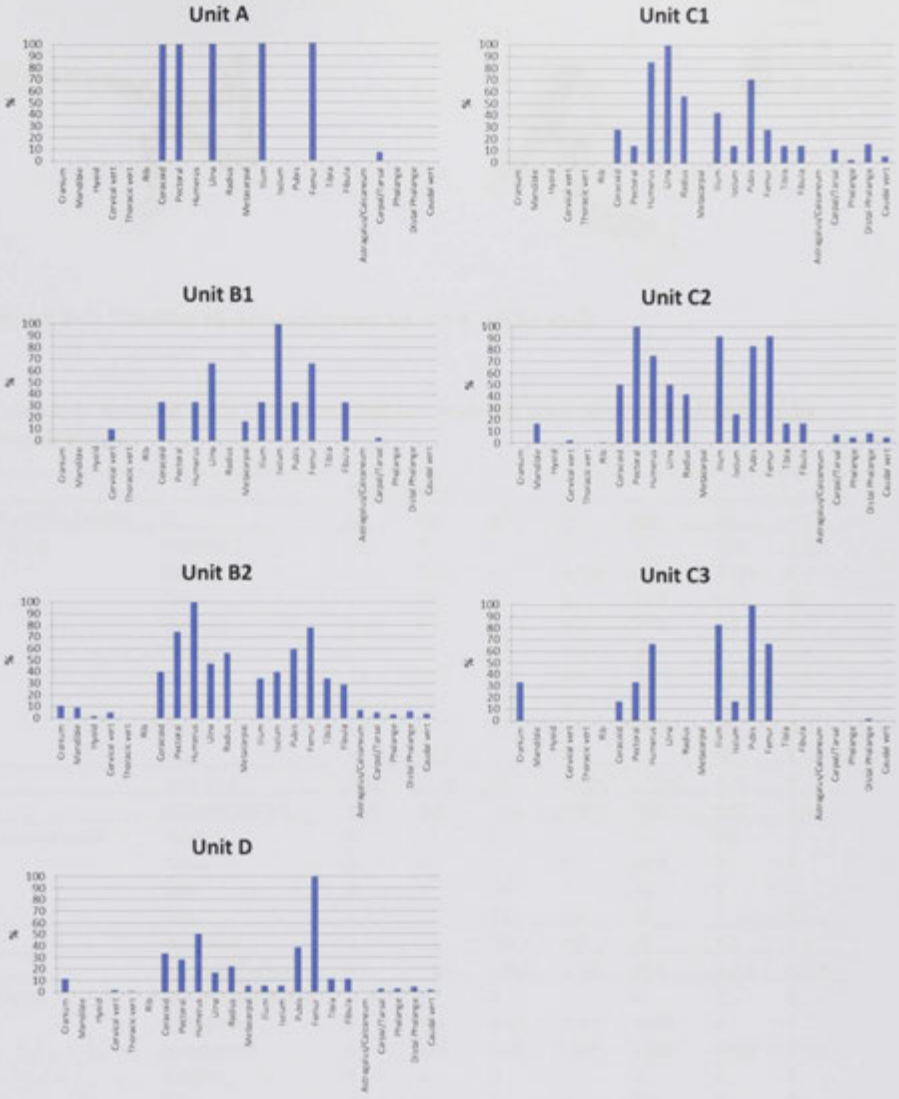


**Figure 8-1: %MAU tortoise skeletal elements by temporal unit (left column: cemetery/post-cemetery, right: Lapita midden).**


**Figure 8-2: Tortoise skeletal elements by meat utility rank**

**Table 8-1: Ranked utility tortoise skeletal elements Sum MAU/NELEMENT by temporal unit.**

| | | Temporal Unit | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Rank/NELEMENT | EL | C3 | C2 | C1 | D | B2 | B1 | A |
| High /9 | Coracoid | 0.5 | 3 | 1 | 3 | 11 | 0.5 | 0.5 |
| | Cervical vert | 0 | 0.14 | 0 | 0.143 | 1.286 | 0.143 | 0 |
| | Femur | 2 | 5.5 | 1 | 9 | 21.5 | 1 | 0.5 |
| | Humerus | 2 | 4.5 | 3 | 4.5 | 27.5 | 0.5 | 0 |
| | Pectoral | 1 | 6 | 0.5 | 2.5 | 20.5 | 0 | 0.5 |
| | Ilium | 2.5 | 5.5 | 1.5 | 0.5 | 9.5 | 0.5 | 0.5 |
| | Ischium | 0.5 | 1.5 | 0.5 | 0.5 | 11 | 1.5 | 0 |
| | Pubis | 3 | 5 | 2.5 | 3.5 | 16.5 | 0.5 | 0 |
| | Rib | 0 | 0.02 | 0 | 0 | 0 | 0 | 0 |
| | Total MAU | 11.5 | 31.16 | 10 | 23.64 | 118.79 | 4.64 | 2 |
| | MAU/NELEMENT | 1.28 | 3.46 | 1.11 | 2.63 | 13.2 | 0.52 | 0.22 |
| Intermediate/4 | Fibula | 0 | 1 | 0.5 | 1 | 8 | 0.5 | 0 |
| | Radius | 0 | 2.5 | 2 | 2 | 15.5 | 0 | 0 |
| | Tibia | 0 | 1 | 0.5 | 1 | 9.5 | 0 | 0 |
| | Ulna | 0 | 3 | 3.5 | 1.5 | 13 | 1 | 0.5 |
| | Total MAU | 0 | 7.5 | 6.5 | 5.5 | 46 | 1.5 | 0.5 |
| | MAU/NELEMENT | 0 | 1.875 | 1.625 | 1.375 | 11.5 | 0.375 | 0.125 |
| low/10 | Astragalus/calcaneus | 0 | 0 | 0 | 0 | 2 | 0 | 0 |
| | Caudal vert | 0 | 0.25 | 0.17 | 0.167 | 1.083 | 0 | 0 |
| | Carpal/tarsal | 0 | 0.42 | 0.39 | 0.231 | 1.308 | 0.039 | 0.039 |
| | Cranium | 1 | 0 | 0 | 1 | 3 | 0 | 0 |
| | Hyoid | 0 | 0 | 0 | 0 | 0.5 | 0 | 0 |
| | Metacarpal | 0 | 0 | 0 | 0.5 | 0 | 0.25 | 0 |
| | Mandible | 0 | 1 | 0 | 0 | 2.5 | 0 | 0 |
| | Phalange | 0 | 0.25 | 0.075 | 0.25 | 0.85 | 0 | 0 |
| | Phalange distal | 0.05 | 0.5 | 0.55 | 0.4 | 1.6 | 0 | 0 |
| | Thoracic vert | 0 | 0 | 0 | 0.071 | 0 | 0 | 0 |
| | Total MAU | 1.05 | 2.42 | 1.185 | 2.62 | 12.84 | 0.29 | 0.039 |
| | MAU/NELEMENT | 0.105 | 0.242 | 0.119 | 0.26 | 1.28 | 0.03 | 0.004 |

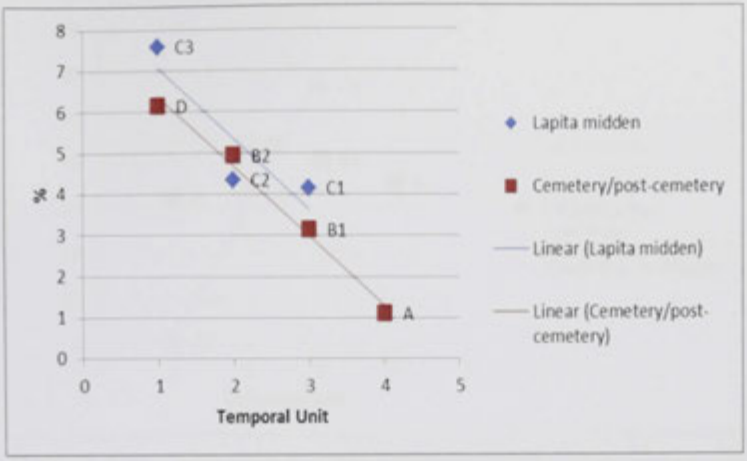


**Figure 8-3: Proportion of Sum MAU/NELEMENT Low ranked utility tortoise skeletal elements by temporal unit**

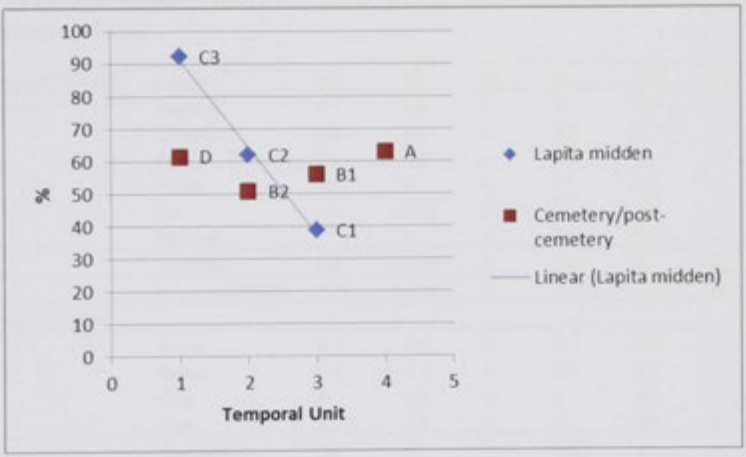


**Figure 8-4: Proportion of Sum MAU/NELEMENT High ranked utility tortoise skeletal elements by temporal unit**

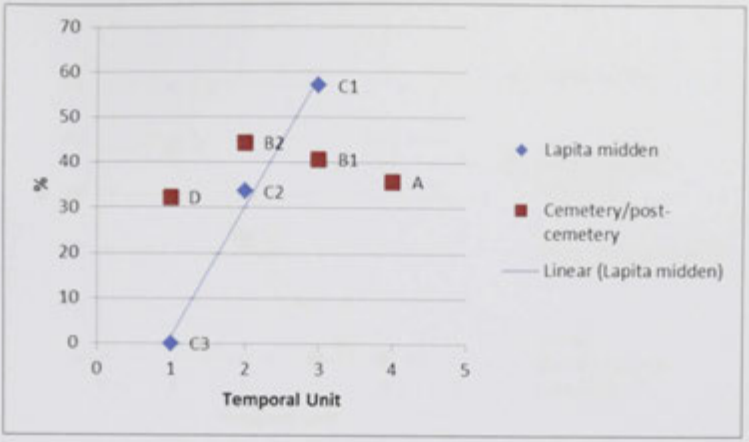


**Figure 8-5: Proportion of Sum MAU/NELEMENT Intermediate ranked utility tortoise skeletal elements by temporal unit**

**Table 8-2: Ranked utility sea turtle skeletal elements Sum MAU/NELEMENT by temporal unit.**

| Rank/NELEMENT | Element | C3 | C2 | C1 | D | B2 | B1 | A |
|---|---|---|---|---|---|---|---|---|
| High/6 | Humerus | 0 | 0.5 | 0 | 0 | 0.5 | 0 | 0 |
| | Coracoid | 0.5 | 0.5 | 0 | 0.5 | 0 | 0 | 0 |
| | Femur | 0.5 | 0.5 | 0 | 0.5 | 0 | 0 | 0 |
| | Pelvis | 0.5 | 1 | 0 | 0 | 0.5 | 0 | 0 |
| | Rib | 0.1 | 0.05 | 0 | 0 | 0 | 0 | 0 |
| | Pectoral | 1 | 0 | 0 | 0.5 | 0 | 0 | 0 |
| | Total MAU | 2.6 | 2.55 | 0 | 1.5 | 1 | 0 | 0 |
| | MAU/NELEMENT | 0.43 | 0.43 | 0 | 0.25 | 0.17 | 0 | 0 |
| Intermediate/4 | | | | | | | | |
| | Fibula | 0 | 0.5 | 0 | 0 | 0.5 | 0 | 0 |
| | Radius | 0.5 | 1.5 | 0 | 0.5 | 0.5 | 0 | 0 |
| | Tibia | 0 | 1.5 | 0 | 1 | 0.5 | 0 | 0 |
| | Ulna | 0 | 1.5 | 0 | 0 | 0.5 | 0 | 0 |
| | Total MAU | 0.5 | 5 | 0 | 1.5 | 2 | 0 | 0 |
| | MAU/NELEMENT | 0.125 | 1.25 | 0 | 0.375 | 0.5 | 0 | 0 |
| Low/8 | | | | | | | | |
| | Phalange | 0.31 | 0.27 | 0.04 | 0.019 | 0.077 | 0.019 | 0 |
| | Carpal/tarsal | 0.04 | 0 | 0 | 0.04 | 0.04 | 0 | 0 |
| | Intermediate carpal | 0 | 0.5 | 0 | 0 | 0.5 | 0 | 0 |
| | Phalange distal | 0.05 | 0 | 0.05 | 0 | 0 | 0 | 0 |
| | Cervical vert | 0 | 0 | 0 | 0 | 0.286 | 0 | 0 |
| | Cervical vert 8 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| | Metacarpal | 1 | 0.5 | 0 | 0 | 0 | 0 | 0 |
| | Ulnare | 0 | 0.5 | 0 | 0 | 0 | 0 | 0 |
| | Caudal vert | 0.25 | 0 | 0 | 0.083 | 0 | 0 | 0 |
| | Total MAU | 2.65 | 2.77 | 0.09 | 0.14 | 0.9 | 0.02 | 0 |
| | MAU/NELEMENT | 0.33 | 0.35 | 0.01 | 0.02 | 0.11 | 0.002 | 0 |

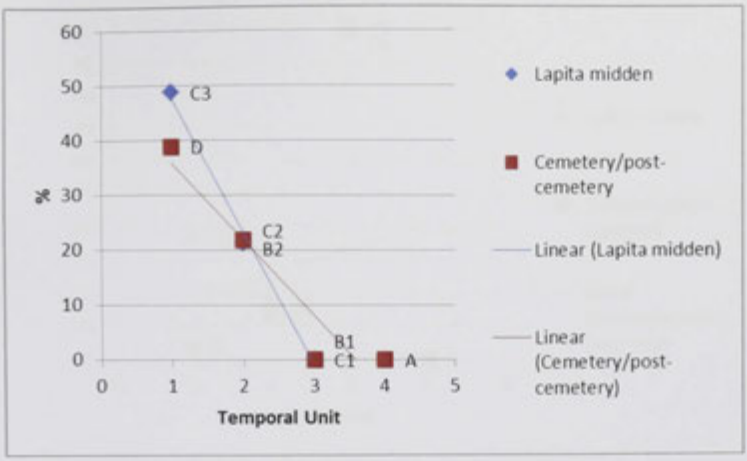


**Figure 8-6: Proportion of Sum MAU/NELEMENT high ranked sea turtle skeletal elements by temporal unit**

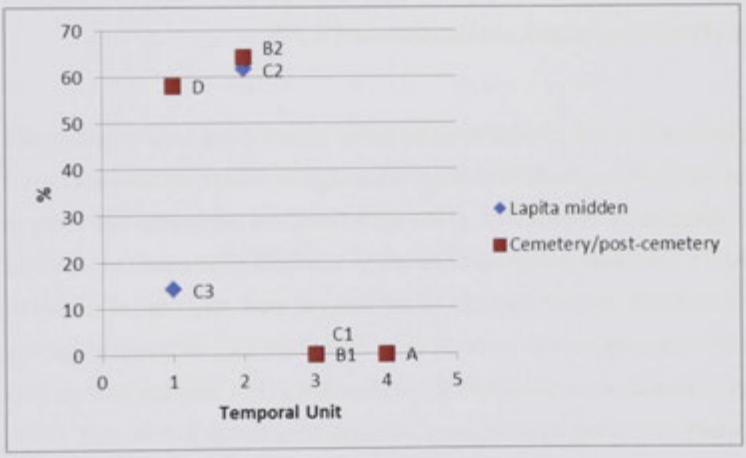


**Figure 8-7: Proportion of Sum MAU/NELEMENT intermediate ranked sea turtle skeletal elements by temporal unit**

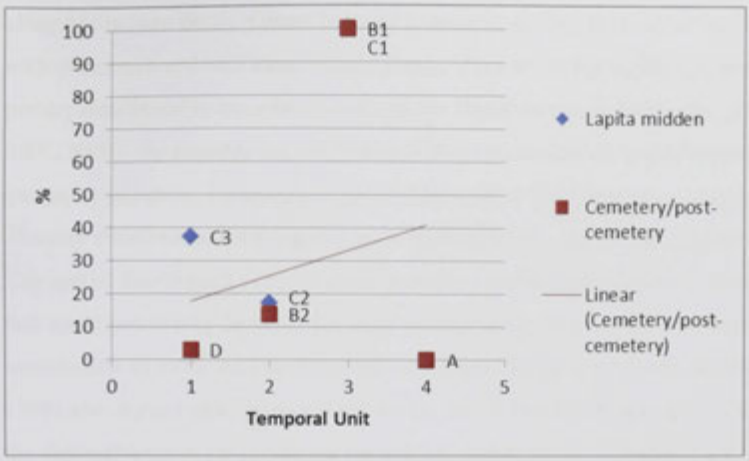


**Figure 8-8: Proportion of Sum MAU/NELEMENT low ranked sea turtle skeletal elements by temporal unit**

### *8.1.2 Non-subsistence based turtle utilization*

Ethnographic accounts in Pacific island societies indicate that in the recent past, sea turtles assumed the mantle of high-status symbols of chiefly power often used in feasts or made into ceremonial artefacts (Allen 2007). Two species of sea turtle, the herbivorous Green turtle *Chelonia mydas* and omnivorous Hawksbill *Eretmochelys imbricata* in particular, were targeted but for differing reasons. While the Green turtles are highly prized for their meat, with up to 50-60 kg of meat produced per individual (Bliege-Bird and Bird 1997), it is uncertain if Hawksbill sea turtles were eaten (Frazier 2004). They do not appear to be desirable to eat, perhaps due to their major diet of toxic sponges. Hawksbill, however, are highly prized in many different cultures for the utility of their shell or scutes which are considered superior to the green turtle (Allen 2007; Frasier 2003, 2004, 2005).

Frazier (2005) reviewed the archaeological evidence worldwide for prehistoric use of sea turtles from the Indian Ocean to the Caribbean and noted various uses for sea turtle shell and long bones made into functional tools including scrapers, net gauges, weaving tablets, adzes, spades, bivalve openers, shells used as vessels for cooking and even shaving implements. He also reported the use of sea turtle shell to make ornaments, game divination counters, and diverse funerary objects, with articulated shells in some cases used to cover graves. In other instances, turtle skulls were placed ceremoniously

alongside human skulls. Given Teouma's status as a substantial early Pacific cemetery with distinctive and well established funerary rites involving highly elaborate decorated pottery distributed in association with graves (Bedford and Spriggs 2007; Bedford et al 2007, 2009), the possible use of tortoise and sea turtle shell as part of these rites is an intriguing prospect. Thousands of unidentified turtle shell fragments are present in the Teouma vertebrate assemblage but were excluded from quantified analysis in this thesis. The spatial distribution of turtle shell in relation to the Lapita burials is a line of enquiry that could potentially demonstrate such an association; but during excavation some associations of turtle shell with burials was noted (White et al 2010). Ambrose (1997, 1999) also argued quite persuasively for the use of Hawksbill sea turtle scutes to make the distinctive tools for producing the dentate stamp motifs on Lapita pots.

At Teouma there is clear evidence for working of turtle shell. A number of intensively worked rectangular turtle shell (carapace and plastron) items (Figures 8-9 and 8-10) were identified within the Lapita midden (adjacent to the cemetery) assemblage in temporal unit C2 and clustered within a few squares C16-C17 indicating a specific turtle shell manufacturing activity area. The shell is tentatively identified as tortoise *cf ?Meiolania damelipi* based on its thin width and surface microstructure, which has the same fibrous texture of the tortoise long bones and appears distinctively different to sea turtle shell and long bones. These small rectangular items of approximately 3-5cm in dimension were clearly worked on two to three sides in a deliberate fashion. It is interpreted here that these were likely cast offs during manufacturing of some kind of decorative ornaments, which may have denoted social status in funerary practices. In Figure 8-9 the intensive cut marks from the manufacturing process are visible and in Figure 8-10 the perfectly smooth edge is visible as a result of sawing with a sharp tool.

The added complexity of turtle utilization for tools, ornaments and displays of chiefly status and power further complicates predictions of turtle optimal foraging. It is extremely difficult to separate competing motivations for the acquisition of these resources. Add in the difficulty of identifying sea turtle to species or distinguishing tortoise from sea turtle shell fragments further complicates the situation. At Teouma, neither Green turtle nor Hawksbill species could be specifically identified due to a lack of cranial and mandible skeletal elements. It is, however, likely that both cultural and economic motivations to target turtles were acted on simultaneously. It is assumed here that turtles were initially selected because they were high-ranked prey in terms of meat

content and always targeted on encounter. However, changes in sea turtle abundance over time could potentially be the result of changing socio-political decisions in acquisition and reservation for special feasts or items of manufacture by controlling elites.


**Figure 8-9: Dorsal view (left) and ventral view (right) worked turtle shell rectangular items cf tortoise ID#1865 square C16, temporal unit C2 (Lapita midden).**


**Figure 8-10: Lateral worked turtle shell rectangular item edge cf tortoise ID#1860 square C17 temporal unit C2 (Lapita midden).**

### *8.1.3 Bird exploitation: Optimal foraging versus costly signalling theory*

The utilization of birds for meat or decorative materials at Teouma is addressed in this section. Feathers have been recorded in widespread cultural use across the globe for thousands of years. Evidence for the use of raptor/corvid bird species to provide large flight feathers for what can only be decorative purposes goes as far back as the Middle Palaeolithic in Europe and the Near East (Finlayson et al 2012), in PalaeoIndian Holocene sites in North America (Bovy 2002), and at Niah Cave in Sarawak on Borneo in the Asia-Pacific since c. 50,000 cal BP (Reynolds et al 2013). They typically argue this because birds of prey, which are not considered human food items, had high proportions of wing bones which in some cases had cut marks observed.

The cultural use of bird feathers, not just from birds of prey, for ornamental purposes has been documented in ethnographic accounts most famously as headdresses by Native North Americans (Howard 1954), as well as cloaks and headdresses worn by Hawaiian royalty (Kirch 1997) and Maori chiefs (Hartnup et al 2011; Harwood 2011), and the trading of Bird of Paradise feathers from New Guinea to SE Asia (Swadling 1996). These accounts all indicate levels of social stratification and political power. The difficulty of obtaining the number of feathers needed for decorative items, especially from scarce species, and the difficultly in making such items, signals their cost and the wealth and status of the individuals who have obtained these items.

In the Pacific, archaeological studies of the use of feathers for such items to demonstrate social status and chiefly power by prehistoric peoples have yet to be demonstrated. There have been small numbers of raptor and corvid bones identified in association with human settlement within the region of the Lapita expansion (see Steadman 2006a for data). Much of this evidence is from pre-Lapita Pleistocene and early Holocene deposits in Near Oceania, while immediately Post-Lapita sites in Vanuatu provide only limited evidence of Barn owl *Tyto alba* and Brown Goshawk *Accipiter fasciatus* (Steadman 2006a). Data elsewhere in Remote Oceania are patchy and limited to palaeofauna in cave deposits from New Caledonia and Tonga, although small amounts of Barn-owl remains have been found in Tongan archaeological sites (Steadman 2006a).

The presence of two bird of prey species at the Teouma Lapita site, the Brown Goshawk and the Barn-owl, present the possibility that the ceremonial use of feathers formed a part of the Lapita culture. Like most raptors/corvids, these bird species are not typical food prey for humans. Barn-owls are still present in the region today and thriving in the human-modified landscapes with abundant rats and squamate lizards to prey on. The small quantities of Australian Barn-owl were identified from the cemetery unit D and within the adjacent Lapita midden unit C2 (NISP=10), as well as in the post-cemetery Lapita midden unit B2 (NISP=3). Small amounts of Brown Goshawk were recovered from the immediately Post-Lapita site of Arapus, northwest Efate coast (Bedford 2006a), and is extirpated from Efate today. Brown Goshawks should have thrived much like Barn-owls in the human modified landscapes. It was likely scarce and impacted by prehistoric human predation and invasive mammal disturbances. At Teouma, Brown Goshawk bones were found in small quantities during both the cemetery and Lapita midden period (NISP=4) and post-cemetery Lapita midden (NISP=15) temporal units.

Testing this hypothesis of raptor feather utilization at Teouma was conducted using the rationale of Finlayson et al (2012). The proportions of skeletal wing elements compared to meaty skeletal elements were used in this argument. Relatively high proportions of non-meaty large flight feather-bearing wing elements relative to meaty elements would indicate the use of feathers. To demonstrate this qualitatively, skeletal element MNE data was converted to MAU to take into account the number of times each bone occurs in the body. These MAU values were arranged into anatomical units they are associated with including head (cranium, mandible), wing (humerus, ulna, radius, carpometacarpal, wing digits), breast (coracoid, sternum, scapula), and upper leg or thigh (femur, pelvis) and lower leg (tibiotarsal, tarsometatarsal, phalanges). These values of MAU for each anatomical unit were then summed and divided by the number of elements (NELEMENT) that occur in each anatomical unit. This is because each anatomical unit is associated with an unequal number of skeletal elements. The most meaty bird anatomical units include the breast and upper leg while the head, wings and lower leg units have the least meat.

While data on cut marks present on bird skeletal elements from Teouma are currently lacking, the focus here is on skeletal element representation within bird anatomical units to understand bird utilization at Teouma and whether it changed over time. As a control, two abundant bird species, the Pacific Imperial Pigeon (Table 8-3, Figure 8-11) from

the forest patch and the Purple Swamphen (Table 8-4, Figure 8-12) from the wetlands patch; both likely to form part of the diet, were used as a point of comparison with the two raptors, the Australian Barn-owl (Table 8-5, Figure 8-13) and the Brown Goshawk (Table 8-6, Figure 8-14) by temporal unit.

The skeletal element representation of non-raptor birds in comparison to birds of prey revealed the expected pattern. The Purple Swamphen and Pacific Imperial Pigeon showed consistent trends for both the cemetery and post-cemetery phases of occupation with generally higher proportions of the meaty breast and thigh anatomical units and less wing elements compared to the Brown Goshawk and to a lesser extent the Australian Barn-owl, which had higher proportions of wing elements. An investigation of concentrations of cut marks on the Brown Goshawk and Barn-owl compared to the Swamphen and Pacific Imperial Pigeon wing skeletal elements would be expected to confirm this.

**Table 8-3: Pacific Imperial Pigeon skeletal elements MNE, by anatomical unit and temporal unit**

| Anatomical unit | Element | C3 | C2 | C1 | D | B2 | B1 | A |
|---|---|---|---|---|---|---|---|---|
| Head | Cranium | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Mandible | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Wing | Humerus | 0 | 1 | 0 | 1 | 2 | 2 | 0 |
| | Radius | 0 | 1 | 0 | 2 | 0 | 0 | 0 |
| | Digit | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Ulna | 2 | 1 | 0 | 0 | 2 | 1 | 0 |
| | Carpometacarpal | 0 | 1 | 0 | 0 | 0 | 2 | 0 |
| Breast | Coracoid | 5 | 6 | 0 | 5 | 14 | 3 | 0 |
| | Scapula | 1 | 3 | 0 | 2 | 5 | 2 | 0 |
| | Sternum | 0 | 0 | 0 | 1 | 3 | 0 | 0 |
| Upper leg | Femur | 1 | 3 | 0 | 0 | 2 | 0 | 0 |
| Lower leg | Tibiotarsal | 0 | 1 | 0 | 0 | 1 | 0 | 0 |
| | Fibula | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| | Tarsometatarsal | 2 | 2 | 0 | 2 | 1 | 0 | 0 |
| | Phalange | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Total | 11 | 20 | 0 | 13 | 30 | 10 | 0 |

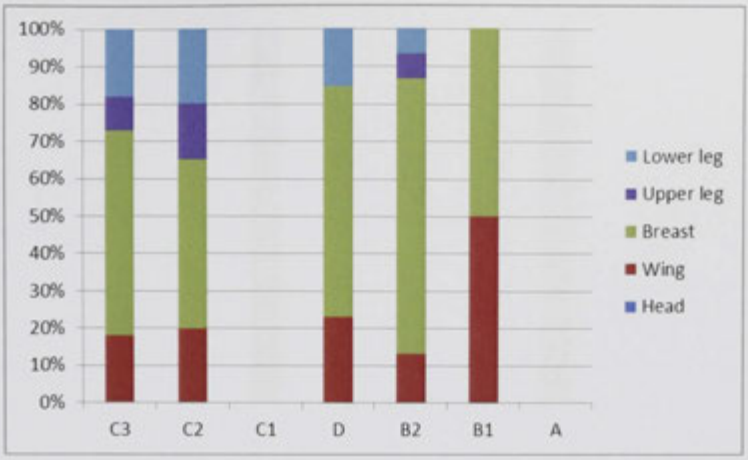


**Figure 8-11: Pacific Imperial Pigeon anatomical unit MNE proportions by temporal unit.**

**Table 8-4: Purple Swamp Hen skeletal elements by anatomical unit MNE and temporal unit.**

| Anatomical unit | Element | C3 | C2 | C1 | D | B2 | B1 | A |
|---|---|---|---|---|---|---|---|---|
| Head | Cranium | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Mandible | 0 | 2 | 0 | 0 | 3 | 1 | 0 |
| Wing | Humerus | 0 | 1 | 0 | 1 | 6 | 3 | 0 |
| | Radius | 0 | 1 | 0 | 0 | 2 | 2 | 0 |
| | Digit | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| | Ulna | 1 | 1 | 1 | 0 | 5 | 1 | 0 |
| | Carpometacarpal | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Breast | Coracoid | 1 | 1 | 1 | 2 | 11 | 4 | 1 |
| | Scapula | 0 | 2 | 2 | 0 | 4 | 1 | 0 |
| | Sternum | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| Upper leg | Femur | 0 | 0 | 0 | 0 | 5 | 0 | 0 |
| Lower leg | Tibiotarsal | 2 | 4 | 1 | 2 | 12 | 2 | 0 |
| | Tarsometatarsal | 0 | 2 | 1 | 4 | 12 | 4 | 1 |
| | Phalange | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| | Total | 4 | 14 | 6 | 9 | 62 | 19 | 2 |

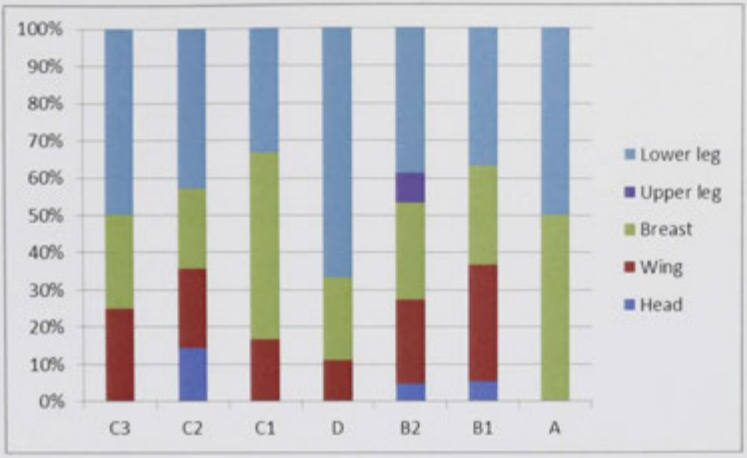


**Figure 8-12: Purple Swamp Hen anatomical unit MNE proportion by temporal unit.**

**Table 8-5: Australian Barn-owl skeletal elements MNE, by anatomical unit and temporal unit**

| Anatomical unit | Element | C3 | C2 | C1 | D | B2 | B1 | A |
|---|---|---|---|---|---|---|---|---|
| Head | Cranium | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| | Mandible | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Wing | Humerus | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Radius | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| | Digit | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Ulna | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| | Carpometacarpal | 0 | 0 | 0 | 1 | 1 | 0 | 0 |
| Breast | Coracoid | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| | Scapula | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Sternum | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Upper leg | Femur | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| Lower leg | Tibiotarsal | 0 | 3 | 0 | 1 | 0 | 0 | 0 |
| | Tarsometatarsal | 0 | 1 | 0 | 1 | 0 | 0 | 0 |
| | Phalange | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Total | 0 | 6 | 0 | 4 | 3 | 0 | 0 |

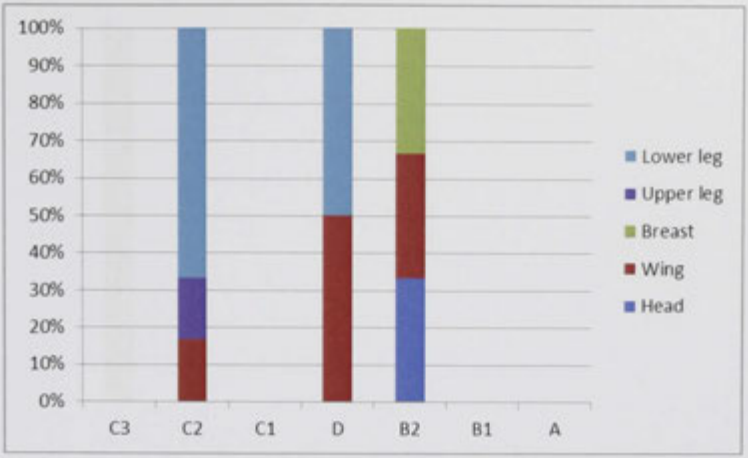


**Figure 8-13: Australian Barn-owl anatomical unit MNE proportions by temporal unit.**

**Table 8-6: Brown Goshawk skeletal elements MNE by anatomical unit and temporal unit.**

| Anatomical unit | Element | C3 | C2 | C1 | D | B2 | B1 | A |
|---|---|---|---|---|---|---|---|---|
| Head | Mandible | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Wing | Humerus | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| | Radius | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Digit | 1 | 0 | 0 | 1 | 1 | 0 | 0 |
| | Ulna | 0 | 0 | 0 | 0 | 2 | 0 | 0 |
| | Carpometacarpal | 0 | 0 | 0 | 0 | 2 | 0 | 0 |
| Breast | Coracoid | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| | Scapula | 0 | 1 | 0 | 0 | 1 | 0 | 0 |
| | Sternum | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Upper leg | Femur | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| Lower leg | Tibiotarsal | 0 | 0 | 0 | 1 | 1 | 0 | 0 |
| | Tarsometatarsal | 0 | 0 | 0 | 0 | 3 | 0 | 0 |
| | Phalange | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Total | 1 | 1 | 0 | 2 | 13 | 0 | 0 |

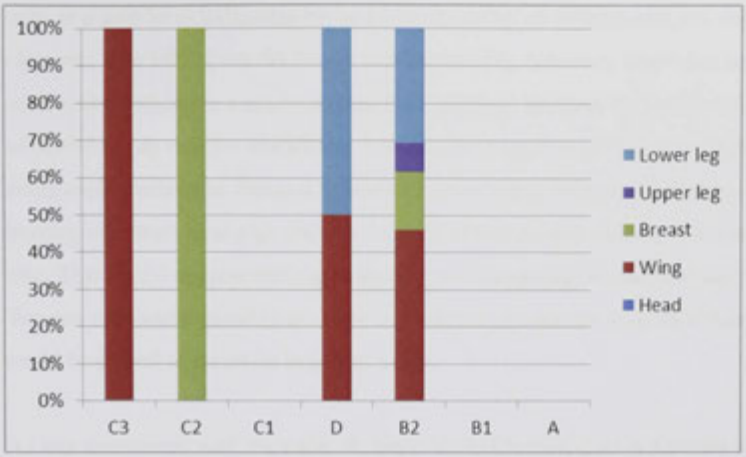


**Figure 8-14: Brown Goshawk anatomical unit MNE proportions by temporal unit.**

### *8.1.4 Pig utilization: The cultural spatio-temporal distribution of mean meat utility*

Here I investigate potential social-political demonstrations of wealth and power distributed within the Teouma Lapita and Post-Lapita spatio-temporal units by measuring variation in pig meat utility (see Chapter 5 for procedures used to measure pig mean meat utility and Table 8-7 for data and calculations). The pig mortality data in Chapter 7 indicated that pigs were closely managed at Teouma for a range of purposes including population control, household consumption, displays of social status and wealth during ceremonial events, and maybe even funerary rites. This would suggest that transport and butchery decisions to reduce significant distance associated costs would not likely apply for pig utilization at Teouma. In fact if pigs were being managed by the inhabitants living at the site, we would expect to find a broad range of skeletal elements that reflect both high and low nutritional value body parts. Alternatively spatio-temporal variation in the deposition of pig anatomical units could potentially be related to various ceremonial activities across the site.

The results of calculating the mean meat utility index are presented on a single scatter-plot in Figure 8-15 where the mean utility value by temporal unit is represented. At the Teouma Lapita site there appears to be a clear pattern. Mean meat utility appears stable during the Lapita cemetery (D) midden (C3-C1) and post-cemetery phase Lapita (B2)

units at a mid-level indicating broad skeletal deposition of high and low value skeletal elements. The MUI from the Erueti midden unit B1, however, was twice as high as the other units, indicating a potential period of feasting. Because it coincides with a period of declining pig relative abundance it could also suggest a period of importation of high value meat portions to Teouma typical of butchery and transport decisions during the hunting of distant feral pigs and the disposal of low quality skeletal portions somewhere else. This would suggest that pig husbandry was declining at this final stage of the Teouma settlement possibly as crops had become the mainstay of subsistence and less could be spared to maintain large pig herds.

As was considered with the turtle skeletal element representation analysis that it is possible that pig skeletal element representation could be the result of post depositional bone destruction rather than reflecting past cultural processes; the densest bones tend to survive in greater frequency than those that are less dense (e.g. Lyman 1994). But in this case it is possible to evaluate the effect of bone destruction on pig bones at Teouma using bone bulk density values from an artiodactyl index developed by Lyman (1982). This artiodactyl index was plotted against the percentage of pig skeletal elements expected to survive in the Teouma archaeological record. Percentage survivorship of each skeletal element is calculated by dividing the observed number of skeletal elements (MNE) by the expected number of skeletal elements, multiplied by 100 to convert the data to proportions so that they are directly comparable between different assemblages. The expected number of skeletal elements is merely the MNI multiplied by the number of times each element is present in an individual skeleton. So if MNI is ten and there are two humeri in an animal, then the expected number of individuals would be twenty. Statistical analysis aimed at testing if there was any significant correlation between skeletal element survivorship and skeletal volume density is presented in Table 8-8. The results indicate that taphonomic bone destruction was not a significant factor in skeletal element composition in any of the temporal units making zooarchaeological inferences about these types of data more valid.

**Table 8-7: Data used to calculate Pig Mean Meat Utility (gm) per temporal unit, unmodified Mean Utility Index (MUI) data after Rowley-Conwy et al 2002, values for anatomical units/elements in MAU, total MNE in bottom row.**

| | | C3 | | C2 | | C1 | | D | | B2 | | B1 | | A | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean MUI | EL | MAU | MUI | MAU | MUI | MAU | MUI | MAU | MUI | MAU | MUI | MAU | MUI | MAU | MUI |
| 2090 | Cranium | 2 | 4180 | 2 | 4180 | 1 | 2090 | 5 | 10450 | 7 | 14630 | 2 | 4180 | 0 | 0 |
| 1970 | Mandible | 1 | 1970 | 4 | 7880 | 1 | 1970 | 6 | 11820 | 5 | 9850 | 3 | 5910 | 1 | 1970 |
| 2360 | Atlas/Axis | 1 | 2360 | 1 | 2360 | 0 | 0 | 1 | 2360 | 5 | 11800 | 1 | 2360 | 1 | 2360 |
| 2230 | Cervical vert 3-7 | 0.4 | 892 | 1.2 | 2676 | 0.6 | 1338 | 0.8 | 1784 | 2.6 | 5798 | 0.2 | 446 | 0.2 | 446 |
| 15260 | Thorax | 0.14 | 2105.88 | 1 | 15260 | 1 | 15260 | 0.42 | 6454.98 | 2 | 30520 | 3 | 45780 | 0.17 | 2624.72 |
| 5765 | Lumbar vert | 0.33 | 1902.45 | 1 | 5765 | 0.5 | 2882.5 | 0.67 | 3845.26 | 2 | 11530 | 0.5 | 2882.5 | 0.33 | 1902.45 |
| 1885 | Scapula | 0 | 0 | 1 | 1885 | 0 | 0 | 0.5 | 942.5 | 4.5 | 8482.5 | 0 | 0 | 0 | 0 |
| 1090 | Humerus | 2 | 2180 | 4 | 4360 | 1 | 1090 | 3 | 3270 | 4 | 4360 | 0 | 0 | 1 | 1090 |
| 410 | Radius/Ulna | 0 | 0 | 3 | 1230 | 1 | 410 | 3 | 1230 | 3.5 | 1435 | 0 | 0 | 0.5 | 205 |
| 130 | Metacarpal/carpal | 0.5 | 65 | 2 | 260 | 1 | 130 | 2 | 260 | 1.5 | 195 | 0.5 | 65 | 0 | 0 |
| 4485 | Sacrum/pelvis | 0 | 0 | 3 | 13455 | 1.5 | 6727.5 | 2.5 | 11212.5 | 3.5 | 15697.5 | 0.5 | 2242.5 | 0 | 0 |
| 4785 | Femur | 0.5 | 2392.5 | 2 | 9570 | 1 | 4785 | 3 | 14355 | 5 | 23925 | 0.5 | 2392.5 | 0 | 0 |
| 780 | Tibia/fibula/tarsal | 0.5 | 390 | 3.5 | 2730 | 1.5 | 1170 | 3.5 | 2730 | 5.5 | 4290 | 1 | 780 | 0 | 0 |
| 135 | Metatarsal | 0 | 0 | 2 | 270 | 1.5 | 202.5 | 1.5 | 202.5 | 3 | 405 | 1 | 135 | 1 | 135 |
| 55 | Phalange | 0.19 | 10.31 | 1.06 | 58.44 | 0.56 | 30.8 | 0.5 | 27.5 | 1.25 | 68.75 | 0.31 | 17.19 | 0.06 | 3.44 |
| | MUI total | | 18448.14 | | 71939.44 | | 38086.3 | | 70944.24 | | 142986.8 | | 67190.69 | | 10736.61 |
| | Total MNE | | 31 | | 170 | | 68 | | 117 | | 255 | | 59 | | 19 |
| | MNE/MUI | | 595.1 | | 423.17 | | 560.09 | | 606.36 | | 560.73 | | 1138.83 | | 565.09 |

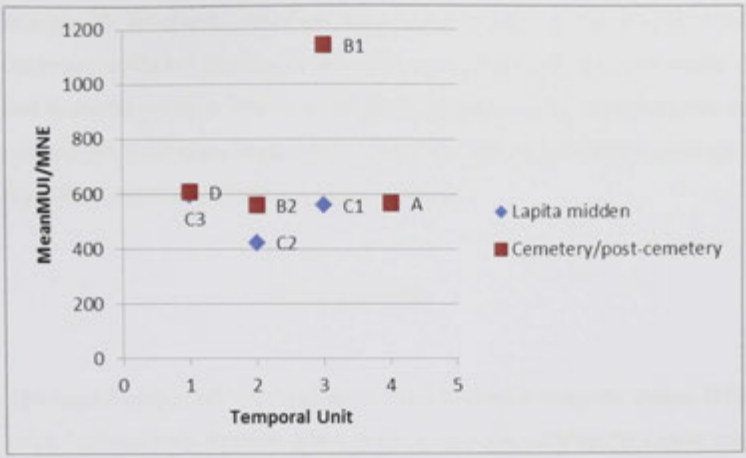


**Figure 8-15: Mean pig meat utility index (MUI) by temporal unit.**

**Table 8-8: Statistical correlation of pig skeletal %survivorship with volume density by temporal unit using Spearman's rho. Bulk density values provided by Lyman (1982).**

| Temporal Unit | rs | p |
|---|---|---|
| A | 0.4 | 0.22 |
| B1 | 0.08 | 0.71 |
| B2 | 0.05 | 0.75 |
| D | 0.22 | 0.19 |
| C1 | 0.36 | 0.06 |
| C2 | 0.16 | 0.31 |
| C3 | 0.33 | 0.21 |

## 8.2 Temporal changes in butchery patterns-Intensification of prey utilization

In the previous skeletal element representation section it was demonstrated, using the Central Place Model, that changes in the utilization of intermediate ranked land and sea turtle skeletal elements indicated a broadening use of meat portions and increasing intensification of turtle (tortoise and sea turtle) carcass utility over time in response to declining abundance of turtles. In Chapter 4 it was predicted (using OFM) that intensification of foraging decisions in response to declining high ranked taxa abundance would correlate with increased carcass processing efforts for meat, marrow and grease removal from a broader range of anatomical units. This, it is reasoned, was to gain more meat, marrow and grease per individual prey once encounter rates decline

to a specific level and returns per individual prey must be maximized. This section examines predicted changes in individual taxa processing intensity within the terrestrial and domestic patches. This is achieved using measures of fragmentation, cut marks and cultural fractures associated with butchery for tortoise and pigs, both large taxa with significant amounts of butchery data available.

### *8.2.1 Tortoise*

The fragmentation rate for tortoises is calculated here using the simple NISP/MNE ratio. Tortoise bone fragmentation certainly increases during the Lapita midden (C3-C1) period (Figure 8-16) but not significantly ($X^2_{trend} = 0.002$, $P = 0.97$; $X^2_{departure} = 2.25$, $P = 0.13$). During the cemetery/post-cemetery units there was also an insignificant result as the fragmentation rate slightly increased from the cemetery (D) to post-cemetery Lapita period (B2), before drastically declining by the Early Erueti period (B1) (cemetery/post-cemetery $X^2_{trend} = 0.1$, $P = 0.75$: $X^2_{departure} = 1.97$, $P = 0.16$). Insignificant yet fluctuating changes in the NISP/MNE ratio gives an indication that fragmentation remained largely consistent over time.

The number of cut marks were counted by anatomical location on each skeletal element and displayed graphically for the Lapita cemetery/midden period (Figure 8-17) and the post-cemetery Lapita period (Figure 8-18). These appear to be concentrated during both periods on the high ranked meaty upper limb bones including the pelvic and pectoral girdles. This indicates two things: One, that processing was concentrated on skeletal elements with the greatest meat mass: Two, by direct implication that cut mark frequencies on tortoise bones at Teouma accurately indicate differences in processing intensity by skeletal element. It appears that cut mark intensity was also significantly more concentrated during the post-cemetery period, although this does not take into account differences in sample sizes (Lapita cemetery/midden NISP=451, post-cemetery NISP=1307). However, even with the discrepancy in sample size between the two phases of occupation, a clear increase in cut mark intensification on meaty high ranked tortoise skeletal elements during the post-cemetery phase is apparent.

To quantify change in cut mark intensity over time, while also improving temporal resolution, an approach was needed to plot proportions of cut mark intensity on a single

scatter plot by temporal unit. In Figure 8-19 the number of cut marks per skeletal element (MNE) was calculated for each temporal unit. The results indicate an increase from C3 to C2 during the Lapita midden units and no obvious change from the cemetery (D) to post-cemetery Lapita midden (B2). Units B1 and A samples (bones with cut marks) were too small and so were not considered in this analysis. This potentially indicates increasing intensity during the Lapita midden period, but remembering the problems with this type of analysis of cut mark intensity described in Chapter 5, other measures are needed.

Temporal changes in tortoise meat removal intensity were measured by calculating the proportion of tortoise MNE with cut marks present (Figure 8-20) which is considered more reliable (see chapter 5). There appears to be a slight decline during the Lapita midden (C3-C1) and a slight increase from the cemetery (D) to post-cemetery Lapita midden (B2). In the case of the Lapita midden, decline in cut mark intensity may be associated with a decline in high ranked skeletal elements and an increase in intermediate ranked elements. This could also possibly be due to inherent intermediate ranked element morphologies or more marginal quantities of meat on these elements on which to focus butchery practices. The increase during the post-cemetery Lapita midden (B1) may represent a minor shift in butchery intensity. Note that cut marks recorded on turtle shell fragments as a result of working into artefacts were not included in these studies because they were not being processed for meat and secondly because of problems in quantifying shell fragments by MNE.

Finally the proportions of cultural butchery fractures versus post-depositional fractures of tortoise skeletal elements was measured (Figure 8-21). The numbers of cultural fractures at Teouma were rather low with most fractures proving to be post-depositional, possibly as a result of frequent tectonic activity. Nevertheless while the proportions of cultural butchery related fractures appeared stable during the cemetery period (D, C3-C1) of occupation, there appears to have been a small increase during the post-cemetery Lapita midden (B2).

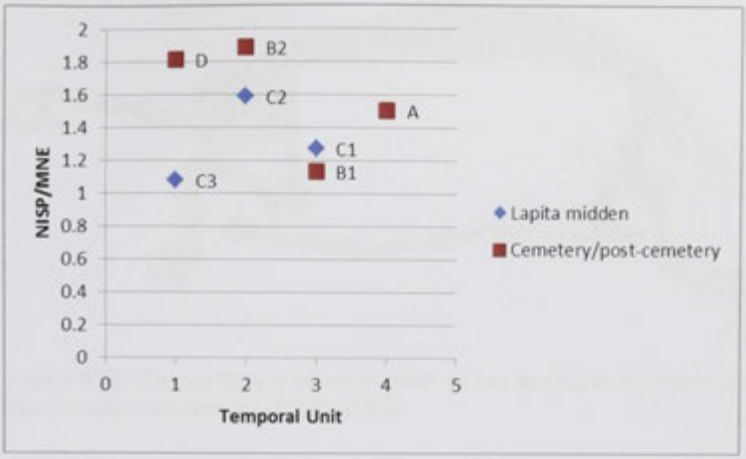


**Figure 8-16: Tortoise fragmentation rate NISP/MNE ratio values by temporal unit ($X^2_{trend}$ = 0.002, P = 0.97; $X^2_{departure}$ = 2.25, P = 0.13; cemetery/post-cemetery $X^2_{trend}$ = 0.1, P = 0.75: $X^2_{departure}$ = 1.97, P = 0.16).**

**Figure 8-17: Cemetery phase number of cut marks by anatomical location and tortoise skeletal element (NISP=451).**

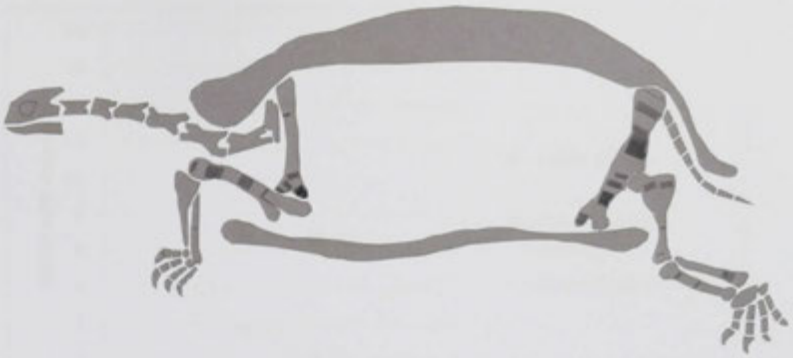

**Figure 8-18: Post-cemetery phase number of cut marks by anatomical location and tortoise skeletal element (NISP=1307).**

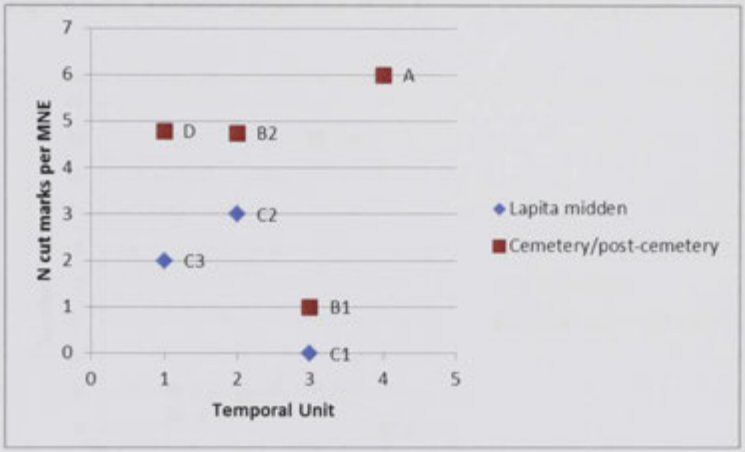


**Figure 8-19: Tortoise number of cut marks per MNE by temporal unit.**

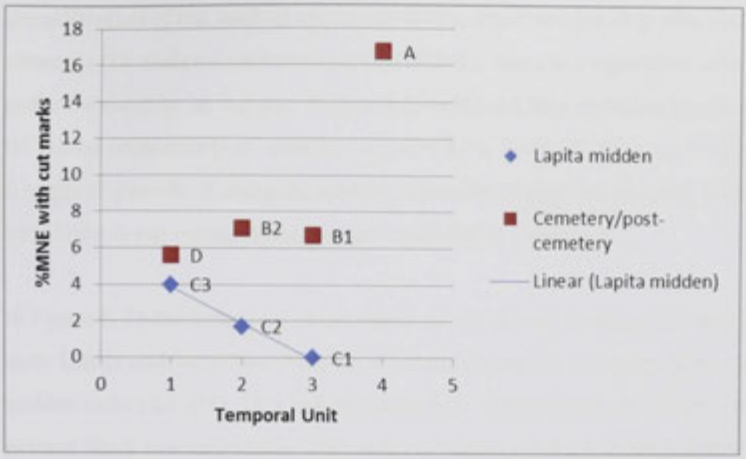


**Figure 8-20: Tortoise proportion of MNE with cut marks present by temporal unit.**

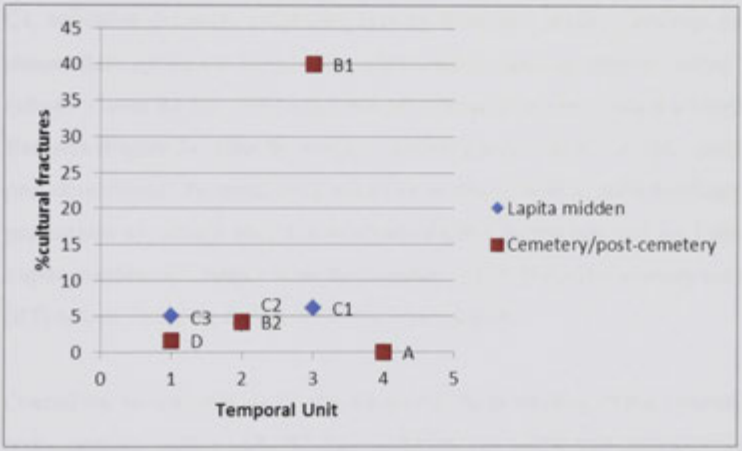


**Figure 8-21: Tortoise proportion of cultural fractures by temporal unit.**

### *8.2.2 Domestic Patch*

Marked increases in intensification of pig skeletal utilization could be related to increasing settlement intensity and declines in foraging efficiency within the domestic and other resource patches. In the case of Teouma, the pig fragmentation rate, as expressed as the NISP/MNE ratio (Figure 22), actually appears to have declined significantly during the Lapita midden period (C3-C1) (Lapita midden $X^2_{trend} = 5.25$, $P = 0.02$), as pig relative abundance was increasing. This could be reflecting de-

intensification of pig skeletal utilization during a period of peak production. During the cemetery (D) and post-cemetery periods (B2-B1) there is a significant non-linear pattern, indicating an increase from unit D to B2 and then a decline by the Early Erueti B1 period (cemetery/post-cemetery $X^2_{trend} = 3.11$, $P = 0.08$; $X^2_{departure} = 15.63$, $P<0.001$). It suggests periods of changing butchery intensity of pigs that possibly relate to variability in pig management practices outlined in Chapter 7.

In Figure 8-23 the frequency of cut marks on pig skeletal elements increases during the early Lapita midden period from C3 to C2 and during the cemetery (D) to post-cemetery midden units (B2- B1). This indicates that those skeletal elements where cut marks are present likely saw an increase in intensity of meat removal over time before declining sharply during the Lapita transition to Early Erueti. Figure 8-24 shows that the proportion of pig bones with cut marks declined during the Lapita midden period C3-C1, indicating declining processing activity. However, during cemetery/ post-cemetery phases there appears to have been a significant increase in butchery during the post-cemetery units B2-B1. The proportion of cultural fractures versus post-depositional fractures (Figure 24) (like the tortoise cultural fracture ratio) was low, pointing towards post-depositional fractures being the most common cause of bone breakage. The proportions of cultural fractures increased slightly between units C3-C2 during the Lapita midden and sharply from the cemetery (D) to the post-cemetery Lapita midden (B2) before declining during the Early Erueti unit B1.

Overall the pattern appears to indicate increasing processing of pig remains during the post-cemetery midden units B2-B1 and declines or mixed data during the Lapita midden (C3-C1).

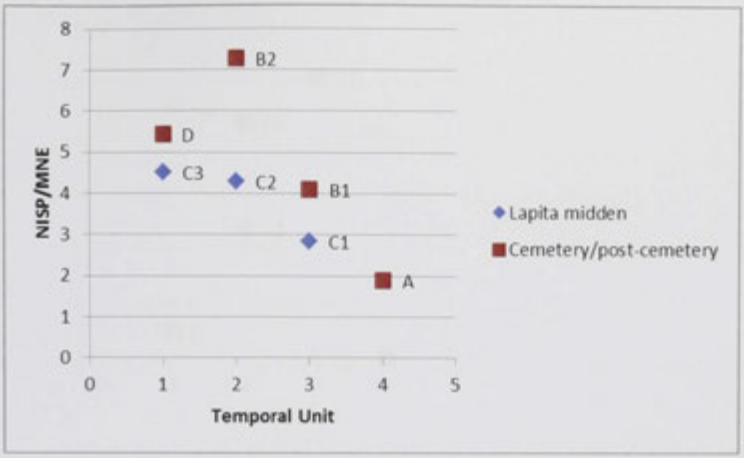


**Figure 8-22: Fragmentation rate for pig bones NISP/MNE by temporal unit (Lapita midden $X^2_{trend} = 5.25$, $P = 0.02$; cemetery/post-cemetery $X^2_{trend} = 3.11$, $P = 0.08$; $X^2_{departure} = 15.63$, $P<0.001$).**

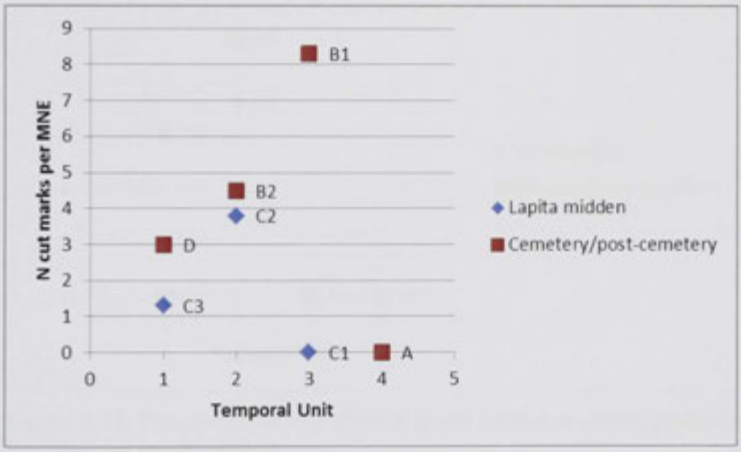


**Figure 8-23: Number of cut marks per MNE for Pig by temporal unit**

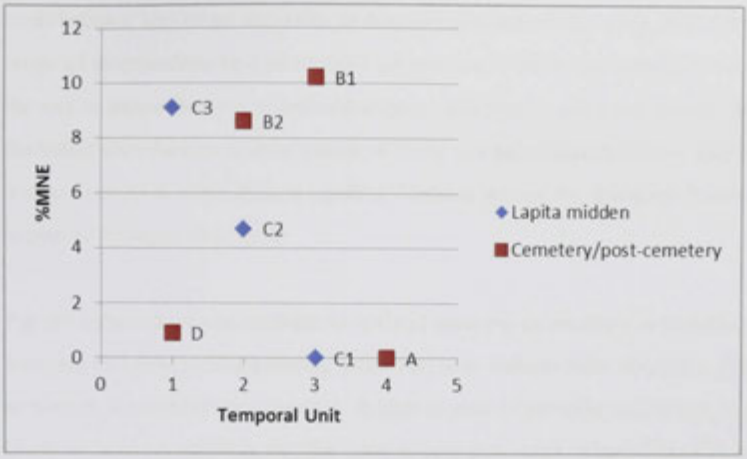


**Figure 8-24: Proportion of Pig MNE with cut marks present by temporal unit**

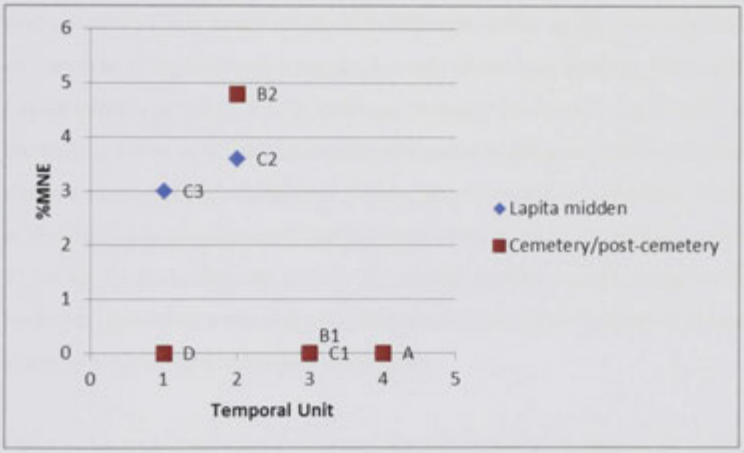


**Figure 8-25: Proportion of Pig MNE cultural fractures versus post-depositional fractures by temporal unit**

## 8.3 Summary

The skeletal element representation and butchery patterns have indicated some clear patterns of animal utilization at Teouma. A significant amount of both tortoise and sea turtle utilization conforms to predictions of OFM in the face of declining abundances. Initially only high ranked tortoise and sea turtle skeletal elements were returning to the site to maximize foraging efficiency by reducing transport costs while low ranked tortoise skeletal elements declined over time. However, over time as distance related

costs became less of an issue due to dramatic declines in foraging efficiency, a broader range of intermediate ranked tortoise and sea turtle skeletal elements were returned to the site as intensification of individual prey occurred to maximize returns from declining abundances. Canoe transport along coastal routes may have aided in reducing transport costs to more distant patches. Tortoise processing intensity, however, did not appear to increase over time.

Pig utilization does not conform to optimal foraging predictions in response to declining foraging efficiency. Management goals varied to include both ritualistic feasting as well as normal household consumption. A high degree of juvenile and infant mortality is likely to have occurred during the early period as a result of non-intensive management methods and selective culling. Alternatively suckling pigs may have been killed for ritualistic mortuary practices. An increase in high ranked pig skeletal elements by the post-cemetery Early Erueti phase (B1) indicates; either an increase in ritualistic feasting or a decline in pig husbandry and an increase in feral pig hunting. During the initial Lapita midden period (C3-C1), butchery intensity declined as pig abundance was increasing. Later as the settlement became more established, butchery intensified during the post-cemetery period (B2-B1). These patterns must be interpreted within the context of declining pig abundance (Chapter 6) and a reduction in young pig mortality (Chapter 7) during the post-cemetery period. The overall pattern strongly suggests that pig husbandry practices were changing during the Post-Lapita transition, in response to changes in social and economic conditions.

Other behaviours practised at Teouma not associated with optimal foraging decisions to maximize meat consumption, include the potential use of bird large flight feathers and turtle shell artefacts to manufacture items which are highly likely to represent symbols of wealth, power and social status.

# 9 Conclusions and Future Directions

In this last chapter I summarize complex Lapita interactions within general ecological resource patches over time and space. Finally, I discuss future research directions and methods that need to be developed to contribute to this work and to improve the veracity of the models applied in this study.

## 9.1 Discussion

This study has provided a quantitative framework which deals with declines in resource abundance as a result of Lapita interactions within the terrestrial and coastal environments. This was possible only by generating predictions from OFM and costly signalling theory that were tested using multiple lines of evidence. These included temporal measures of biodiversity and relative taxonomic abundance, anatomical structure, species demographic composition, changes in large bodied animal processing intensity, and the presence/absence of symbols of wealth and power. This allowed the successful quantification and explanation of temporal variability in foraging and animal husbandry behaviour during the Lapita/Post-Lapita transition at Teouma, while also considering alternative and more unpredictable socio-cultural variables.

The Teouma archaeological record is cumulative with only broadly defined absolute age periods c. 3000-2500 BP. However, it is represented by distinct cultural deposits based on deposition history and depth, combined with well-established ceramic sequences that suggest very short but discretely defined time periods. The vertebrate remains were very well preserved due to unique deposition history and neutral soil conditions, with only minor weathering observed. While the vertebrate remains appear to have suffered extensive post-depositional breakage, this does not appear to have resulted in significant bone destruction, at least not for pig skeletal elements. Such fine grained temporal resolution coupled with excellent preservation conditions and large sample sizes at Teouma provides what is generally an extremely rare situation, where the investigation of rapid change in aspects of material culture and subsistence economy at a Lapita site is possible.

The results of this thesis supports previous isotopic evidence (Bentley et al 2007; Valentin et al 2010; Kinaston 2010) that the range of Lapita subsistence patterns at Teouma conform to the mixed Lapita economy model (e.g. Kennett et al 2006; Kinaston et al 2014), where broad spectrum foraging of marine and terrestrial resources and food production were practiced. But this mixed economy model is necessarily vague and somewhat reductionist, as the isotope evidence also suggests some variability of diet within the Teouma population based on ecology, social factors, gender-specific diets and mobile foraging decisions (Bentley et al 2007; Kinaston 2010; Valentin et al 2010). This thesis provides a more detailed understanding of how early colonizing Lapita populations at Teouma structured their protein and fat resource acquisition strategies.

This finer detail has significantly added to the understanding of subsistence and social behaviour during the colonization process of Lapita expansion into Vanuatu and the Pacific, as well as ecological impacts and subsequent changes in subsistence behaviour. It has also tested a framework for integrating managed domestic and commensal animals within optimal foraging models for the first time, and this has added significantly to our understanding of the process of animal husbandry development in relation to foraging behaviour. The results of which indicate that Lapita subsistence behaviour was fluid and capable of adjusting to rapidly changing ecological and cultural conditions across the landscape as a result of human-induced resource depression and habitat destruction or cultural displays of social status. The latter suggests that sociocultural aspects of animal utilization may have been related to funerary rites during the Lapita cemetery period.

Teouma represents an established permanent settlement situated in a sheltered harbour close to abundant coastal and terrestrial resources on the most ecologically-rich side of Efate Island. Lapita subsistence strategies targeted mostly small game (fruit bats and birds), but also specialized on large game reptiles (tortoises, sea turtles and crocodiles) and introduced commensal animals (domestic pigs, Pacific rat, New Guinea Spiny rat, domestic chicken) in patchy spatial distributions in a way that maximized foraging efficiency. In most cases, subsistence was focused on resource patches that provided the highest net protein and fat returns. These can be divided into three broad temporal exploitation 'phases' representing major shifts in subsistence behaviour, termed here exploitation phase 1 (EP1), 2 (EP2) and 3 (EP3). EP1 covers the early Lapita cemetery and midden period including temporal units D, C3-C1. EP2 covers the post-cemetery

Lapita temporal unit B2 which appears to be a later or partially overlapping Lapita midden period and EP3 covers the upper post-cemetery midden which is a Post-Lapita Early Erueti temporal unit B1.

### *9.1.1Exploitation Phase 1 (EP1) Temporal Units D, C3-C1*

Initially, early Lapita foraging behaviour during the Lapita cemetery period of settlement was uneven and more specialized on concentrated proximal 'fruit bat roosts' and 'sea turtle nest' resource patches situated in predictable locations. Fruit bats in the terrestrial patch were the dominant resource utilized, and despite their small-sized meat packages had low cost attributes that (combined with their dense abundance) allowed high net returns through mass harvesting. Large-bodied sea turtles concentrated in nesting colonies also figured quite prominently in the Lapita subsistence economy early on but declined very rapidly as a result of human exploitation by the end of the Lapita cemetery (D) and midden (C3-C1) period. Large-bodied crocodiles were not abundant within the environment and disappeared very quickly from the archaeological record during this phase.

It appears that settlement intensity increased during the early Lapita phase as evidenced by the rapid increase in faunal deposition, and the adjacent cemetery (D) suggests rapid population expansion. As foraging intensity and diet breadth in the terrestrial patch increased, overall foraging efficiency appeared to be declining as a result of resource depression and apparent agriculturally induced landscape change and habitat modification. This was evidenced by the rapid decline of forest bird abundance relative to wetland birds and, attributed largely to localized habitat destruction. By the end of the cemetery (D) and Lapita midden (C3-C1) period, a number of bird and fruit bat species had disappeared from the archaeological record and remain extinct or extirpated from Vanuatu today. Initially during this period, large-bodied tortoises did not form a significant part of foraging behaviour because of distance-related costs, which were reduced by butchery and transport of only high-quality meat portions back to the site. The implication is that the immediate surrounding area around the Teouma basin had already been depleted by slightly earlier foraging behaviour from another settlement location. However, this situation began to change during this period, as increasing

proportions of tortoises formed part of the diet and a broader range of intermediate ranked meat portions were returned to the site representing intensification of tortoise exploitation of distant tortoise patches as distance related costs became less of an issue. This continued with the help of water transport in the face of declining foraging efficiency of fruit bat and sea turtle resource patches. The two introduced rat species (the Pacific rat and New Guinea Spiny rat) appeared to decline in abundance, although the New Guinea Spiny rat increased in proportion relative to the Pacific rat possibly as a result of differential predation to target its much larger meat package.

Overall the terrestrial patch declined relative to the domestic patch as more time was spent on food production in response to declining foraging efficiency. In the domestic patch, pig production was becoming more specialized as horticulture was being established. As pig abundance was increasing rapidly during this period, young pig mortality increased, and pig butchery intensity declined. Young pig mortality possibly occurred due to nutrient deficiencies and/or selective culling presumably to reduce labour costs and tropic competition with humans during a period of higher foraging efficiency in other resource patches. Alternatively this could represent social ritualized uses of young pigs. During this same period social-cultural aspects of pig husbandry became embedded within the Lapita economic system. Other non-optimal aspects being practiced during this period included the limited use of bird feathers and turtle shell to manufacture items presumably to display social status.

### *9.1.2 Exploitation phase 2 (EP2) Temporal Unit B2*

After the Teouma cemetery period ended, settlement intensity dramatically increased as a later Lapita (B2) settlement expanded in a northwest direction away from the earlier Lapita midden area and over the top of the cemetery. The rapid build-up of Lapita midden deposition above the cemetery indicates that the population at Teouma grew rapidly. Tortoise exploitation was at its height, despite declines in mean age and the distance related costs to acquire them, a testament to the impact that Lapita people were having on tortoise ecology. Intensification of tortoise exploitation clearly continued during this period. As proximal fruit bat and sea turtle resources declined transport cost decisions became less of a factor. This is reflected in increasing proportions of intermediate ranked skeletal elements and declining low ranked skeletal elements being

returned to the site over time. Changes in fruit bat behaviour in response to human predation may also have been affecting foraging efficiency. The sea turtle population was still declining as sea turtle intensification strategies continued. Forest birds continued to decline relative to wetland birds, an indication of the cumulative impact that Lapita horticultural practices were having on local forest habitats. Several more bird species disappeared from the record during this period including the Tongan tooth-billed pigeon. Foraging efficiency was declining as subsistence became more even and focused on a broader range of taxa.

In the domestic patch food production continued to become more specialized on pigs as pig relative abundance was at its height and pigs fulfilled their socio-economic multifunctional role in the Lapita society for household consumption and displays of economic wealth and power. Infant pig mortality improved, either because more established gardens increased nutrients and improved health, or pigs may have become less intensively managed by this stage. In response to declining foraging efficiency, pigs were butchered more intensively to maximize protein returns. In response to resource depression in the terrestrial and coastal resource patches, human predation on rats increased and this had an impact on demography as the rat population started to decline in age. As fewer rats were reaching mature adulthood, the larger Spiny New Guinea rat population had started to decline relative to the Pacific rat as a result of resource depression.

### *9.1.3 Exploitation Phase 3 (EP3) Temporal Unit B1*

By EP3, however, a change in subsistence had occurred which coincided with the transition to Post-Lapita (Early Erueti) settlement, characterized by a dramatic fall in foraging efficiency. Faunal deposits had become sparse despite the continued rapid deposition of coral rubble, midden and anthropogenic sediment related to intensive settlement. Localized ecologies had been reduced in quality as a result of continued human foraging and habitat destruction. By this stage only opportunistic exploitation of sea turtles feeding on the reef or in the harbour were being targeted, but in much smaller numbers with a much lower foraging efficiency. The giant tortoise ecology was devastated and either finished or on the brink of extinction. Subsequent coevolved and co-dependent ecologies at this point may also have collapsed.

Pig production also appears to have declined and pig butchery continued to intensify as rat populations continued to be affected by human activity. The settlement appears to have been winding down by this stage and likely to be focused on vegetable consumption, while an increase in high ranked pig meat utility portions is quite dramatic possibly due to a switch to feral pig hunting and the decision to reduce transport costs or the importation of high ranked meat portions for ritualistic feasting. By the end of this phase the Teouma settlement was abandoned for more fertile fields to improve foraging efficiency or to move closer to the prograding shoreline.

## 9.2 Concluding remarks

This thesis represents a rather novel and experimental incorporation of a Human Behavioural Ecology framework to Lapita/Post-Lapita mixed economic subsistence systems. Such an approach is significant in the way ecological interactions have been quantified and reported on to explain change during Lapita colonisation and settlement through a transition to Post-Lapita. It has facilitated a detailed understanding of the fluid way Lapita people spatially structured their subsistence adaptations and ecological interactions with the terrestrial, coastal, and domestic resource patches across the landscape over time at Teouma. Subsistence choices were largely made to optimize net returns of protein and fat, which was dependent on the encounter rates of high ranked taxa and post encounter net return rates between these different resource patches. It was also demonstrated how OFM can also be used in conjunction with social theories such as costly signalling theory to interpret patterns of Lapita resource use. Humans are capable of a range of behaviours - not just economically-optimal choices - and there is certainly a lot of evidence for symbolic and ritual behaviour at Teouma; decorated Lapita pottery and shell jewellery have been found associated with mortuary activity (Bedford and Spriggs 2007, Bedford et al 2006, Bedford et al 2009).

In this thesis there are also evident patterns of animal utilization that do not correspond to optimal foraging predictions but nonetheless are evolutionary in the sense that these behaviours improve the chances of reproduction and survival through social interaction. This was evidenced from patterns of utilization of birds of prey interpreted as feather acquisition, turtle shell decorative objects and finally pig management strategies

incorporating mature pigs interpreted as symbolizing wealth and power in feasting rituals. All of these are considered demonstrations of costly signalling and social stratification to improve reproductive fitness. Ultimately the rapid and detrimental effect Lapita resource acquisition had on the ecology of Efate Island, whether it was optimally or socially motivated, and how this resulted in economic changes, has been established in detail.

The economic patterns at Teouma had important implications for changes in settlement patterns in the area which were structured spatially to access rich resource patches. The establishment of sedentary farm settlements in these locations, practicing shifting horticulture and pig husbandry, was also a priority. The apparent abandonment of Teouma when resources became depleted strikes a similar chord with subsistence related settlement pattern changes in New Zealand (Anderson and Smith 1996; Nagaoka 2000). The pattern of Teouma settlement conforms to the ideal free distribution model used in the southwest Pacific (Allen 2012; Kennett et al 2006) where the most productive resource patches were selected for exploitation resulting in resource patch depression. After a series of maximizing behavioural decisions in relation to a changing set of ecological conditions, it is clear that the Post-Lapita inhabitants reached a point where foraging efficiency had declined and settlement population had increased. A shift in location was both preferable and possible to resource patches or regions where they could sustain their standard of living through foraging and agriculture.

Resource depression and declines in foraging efficiency have also been casually linked elsewhere with various studies of cultural transitions, including the adoption of agriculture, technological changes, increased warfare, declining health, emergence of socio-political complexity, rise in social inequality, and changes in material culture (Stiner et al 2000; Marean and Assefa 1999; Hildebrandt and Jones 1992; Raab et al 1995; Broughton and O'Connell 1999; Bird and O'Connell 2006; Broughton et al 2010). Societal changes also coincide with resource depression at Teouma. Rapid changes in ceramic sequences from early Lapita dentate stamped ceramics to later Arapus and Early Erueti styles occurred during the post-cemetery transition which corresponds to dramatic shifts in subsistence behaviour seen by EP3. Generally ceramic decorative design and techniques became more simplified and pot forms became increasingly utilitarian in function over time (Bedford et al 2007).

Somehow this apparent Post-Lapita decline in social stratification at Teouma, noted by others elsewhere during the Lapita expansion (Kirch 1988b), is associated with declines in foraging efficiency after the cemetery had lost its ritual and symbolic importance. The implications are that changes in foraging behaviour at Teouma are related to decisions to improve foraging efficiency in the context of declining resources, rather than costly signalling of wealth and power since social stratification was declining. This shift in subsistence also does not appear related to any change in technology as the most abundant fauna exploited at Teouma (fruit bats, tortoises and sea turtles) do not require any complicated technology for capture and processing, and changes in technology were not found in the Teouma archaeological record.

It is also possible that pathologies discovered on the human skeletal remains recovered from the Teouma cemetery, as well as signs of maternal in utero stress which indicate signs of chronic health issues suffered during colonization (Buckley 2007; Buckley et al 2008; Kinaston et al 2009) could also be related to declines in foraging efficiency during the Lapita period of occupation. It would be interesting to see if signs of ill health declined even further during the post-cemetery period at Teouma if such datasets were available.

The sequence at Teouma has remarkable parallels with developments in the modern world with regards to population growth and sustainability of habitation and resource utilization. Today there is widespread concern over increasing human populations and unsustainable resource consumption that is rapidly damaging the environment and diminishing ecological systems and biological diversity referred to as the 6th mass extinction event of the last fifty years (Pott 2014). Discussion has been driven by the scientific community on how best to find solutions to the current trajectory by reducing climate change associated emissions, improving food production sustainability (e.g. Pimentel and Pimentel 2003) as well as biological conservation and ecological restoration (e.g. Griffiths et al 2013; Hunter et al 2013; Pedrono et al 2013).

The growing importance of the applied zooarchaeology field to provide datasets on trajectories of long term human-ecological interactions relevant to these modern discussions on sustainability and conservation science is also gaining traction (Wolverton and Lyman 2012). These past trajectories serve as key accounts of past distributions of biological diversity and of the rapid consequences of unrestrained

resource acquisition. Teouma presents another model for modern long term trajectories of resource use within tropical island communities. The long term cumulative effects of Lapita ecological interactions at Teouma on the environment and society have been proven to be quite debilitating. These patterns of uneven use of initially abundant resources appear to lead to periods of instability in socio-economic and ecological systems with long term implications for the sustainability of such systems and future adaptations needed to ensure the continued success of human settlement.

## 9.3 Future directions

There are many future directions that need to be taken to build on this research in a way that continuously improves understanding of Lapita subsistence strategies and how they changed. There are a range of research avenues raised by this thesis with more questions that need answering about Teouma foraging. These include; additional analysis of the Teouma fauna; improving the quality of some of the interpretations through further ecological research to reduce some of the assumptions; more regional studies analysing additional Lapita sites throughout Vanuatu and the western Pacific, and using integrated datasets from multiple lines of analysis in comparison to faunal datasets to link subsistence change more closely to other aspects of change, be they dietary, cultural, biological, or health-related.

First of all, to provide a complete picture of optimal foraging and subsistence patterns at Teouma, additional analyses need to be undertaken. This thesis has focussed on the terrestrial resource patch, the domestic patch and on only a portion of the coastal patch. But as was established in Chapter 2, fish and shellfish were significant resources exploited by the Lapita colonists throughout their expansion and could be expected to have played a significant role in foraging decisions within the coastal patch at Teouma. Large numbers of fish bones and shell have been recovered and are awaiting analysis. This is not surprising considering the location of the Teouma site within the sheltered Teouma harbour, adjacent to the beach and considering the maritime tradition of Lapita culture. To complete the model, consideration needs to be made concerning foraging decisions in inshore and offshore marine patches, as well as coastal littoral patch decisions. It is crucial that these data are used to test how much time was spent foraging in these patches compared with the terrestrial, coastal and domestic patch data in this

thesis so that a complete picture of resource patch exploitation is available. Until this happens many questions remain unanswered.

Other forms of intra-site analysis at Teouma could add to knowledge of Lapita utilization of animals. First of all a more fine-grained spatial analysis of faunal remains at Teouma is needed to identify in more detail the spatial associations of faunal remains distributed at the site. This is possible because of the excavation by grid system offering 1 x 1 $m^2$ spatial resolution. This will allow the identification of spatial patterns by linking of faunal geodatabases within ArcGIS to create maps showing the distribution of faunal attributes spatially. The faunal geodatabase could potentially delineate faunal processing activity areas or consumption waste areas associated with feasts. It could also potentially detect patterns of faunal remains in association with the burials within the cemetery and spatial patterns between the cemetery area and the adjacent Lapita midden. These patterns could potentially link faunal (including turtle shell) remains more directly to symbolic and ritual mortuary practices as indicated by the distribution of higher quantities of infant pig remains in the cemetery area noted in Chapters 7 and 8.

Taphonomy was not a major focus of this thesis, although cultural modifications of bone at Teouma such as cut mark orientation and frequency and fracture morphology data were used to indicate changes in processing intensity over time. Bone density correlations with pig bone survivorship were also used to demonstrate that skeletal element frequencies were not a result of bone destruction. Additional analyses were also conducted but not reported on in this thesis, which could provide further information on how animals were being processed for consumption. These data include burn marks and gnaw patterns. There are instances in the literature indicating that tortoises were sometimes cooked upside down in their shell over a fire, which would result in burn marks on the dorsal side of tortoise shells (Blasco 2008). A closer look at the burn patterns on turtle shell would determine if this method of cooking turtles was practiced at Teouma. Human chew marks were also recorded on the ends of fruit bat long bones indicating that processing for consumption was minimal; these data will be described in future. In Chapter 8 it was suggested that feathers from birds of prey were being used for decorative purposes based on the anatomical units being discarded at the site. This analysis would be strengthened by reanalysing skeletal elements from these taxa to

determine if cut mark frequencies were present in greater proportions on the wing skeletal elements.

Identification issues also need to be further defined for the giant tortoise and fruit bat species for a finer resolution of ecological interactions, as well as contributing to understanding the biogeographical distribution of these fauna at the time of Lapita arrival. A range of distinct fruit bat species were identified as type specimens only and in future these species need to be compared to extant specimens in museum collections to distinguish which species have disappeared, and so new species can then be described and classified taxonomically and anatomically. This would also provide a better understanding of fruit bat diversity present in Vanuatu before human arrival. In the case of the giant Vanuatu tortoise, its taxonomic origins are uncertain, with the old continental source via Australia and New Caledonia the most likely direction, though New Guinea and the Solomon Islands and the neotropics from the east via Polynesia are the other possibilities. Taxonomic comparisons with tortoise species from these regions from fossil material held in museums, combined with mtDNA analysis could potentially hold the key to this mystery. The identification of pre-human natural sink holes with well-preserved sub-fossil vertebrate remains would also be very beneficial for a more rounded understanding of tortoise and land crocodile skeletal morphology and biogeographical origins and distribution within regional ecology. Also a closer examination of crocodile morphology and taxonomy to distinguish saltwater crocodile from extinct dwarf terrestrial crocodile is important for more fine grained ecological and biogeographical interpretations.

The relative net return rates for fruit bats and tortoises, rats and pigs could be better understood. Detailed experimental studies or recording of contemporary activities could provide more accurate measures of the net foraging return rates, once costs and benefits of search, capture, travel, processing and consumption are taken into account. This would provide far more detailed estimates of relative return rates for these taxa and give a much more realistic method to rank and thus eliminate assumptions of ranking based solely on prey size. This would strengthen the interpretations of changes in foraging efficiency over time. Interpretations of prey rankings by size versus potential for mass harvesting could also potentially be discerned.

The current research has revealed a lack of knowledge worldwide on the relationship between nutritional utility and skeletal elements for turtles. In Chapter 8, I used an ordinal classification system of high-, intermediate- and low-ranked skeletal elements to understand transport and butchery decisions outlined in Chapter 5. More precise measurements of meat quantity per skeletal unit would reduce some of the assumptions I had to make with this ranking classification system and would also make the data much more easily presentable on one graph, since meat utility indexes typically consist of just one value. This would require actualistic studies to measure the meat weights per skeletal element for comparable tortoises and sea turtles to create a Meat Utility Index (MUI) and would greatly strengthen the data for ranking skeletal elements and interpretations of central place foraging. There is also a lack of volume density data for turtle skeletal elements such as those available for a wide range of large mammals (e.g. Lyman 1982, 1994). Such volume density measurements need to be measured on a wide range of tortoise and sea turtle skeletal elements, because without these data it has been assumed that skeletal element representation was a result of human butchery and transport. It could equally be the result of bone destruction. Bone density values for turtle skeletal elements would greatly improve the validity of the interpretations about butchery and transport decisions for turtle utilization.

After these procedural issues are addressed, research focused on locating and excavating similar deposits of well preserved and stratified remains in other parts of Vanuatu and the Pacific need to be undertaken. Regional differences in ecology are likely as a result of environmental, climatic and cultural variability throughout the Pacific. In Vanuatu this regional variability consists of decreasing ecological diversity and richness correlated to decreasing temperature, precipitation and seasonality from northern to southern Vanuatu (e.g. Hamilton et al 2010). This is expected to result in variation in cultural responses to subsistence and settlement patterns by latitude within the Vanuatu archipelago during the Lapita colonization process and contribute to the development of distinctive cultural trajectories on different islands. While central and parts of northern Vanuatu have seen some important archaeological focus, more research in the northern islands (especially on Santo and the Banks Islands and Torres Islands, and in southern Vanuatu) is needed to test these predictions. Variability is also expected regionally along the west to east extent of the Lapita expansion. Building on this work could expand into more widespread regional studies that would help explain subsistence

change within a range of different environments, reflecting various ecological adaptations and cultural developments over time and space.

Finally, further research linking subsistence patterns with changes in material culture at Teouma and other archaeological sites in Vanuatu could also be undertaken as a very productive field in which to link subsistence change more explicitly to cultural change. There has already been an increasing rise in HBE research that integrates material culture data sets (such as stone technology attributes) with faunal data within abundance indexes. These have demonstrated that subsistence, settlement and lithic procurement and tool use are linked more explicitly than current generalizations (e.g. Knell and Hill 2012). In Vanuatu, changes in ceramic style and form appear to suggest rapid (see Bedford 2006a, 2007; Bedford et al 2009) changes in subsistence patterns demonstrated here, suggesting that the two could be linked. At Teouma the transition between the post-cemetery Lapita and Early Erueti periods appears to be the point where the most dramatic shift in material culture and subsistence occurred. A more explicit attempt to link these two datasets could potentially be attempted using optimal foraging abundance indexes, where ceramic style and form attributes could be quantified and measured relative to faunal datasets by temporal unit. In this way relationships between changes in ceramic design and use with foraging efficiency could be measured and increasing simplification of design and functional use of pottery could be more explicitly related to declining foraging efficiency over time.

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